Anode Diameter Reduction, the Effect on Resistance	Rev 0.0	22 Nov 2005

Objective: **Demonstrate that a modest reduction of diameter of an anode will have a minor effect on the overall resistance of the impressed current cathodic protection system.**

This demonstration is based on resistance formulas, and an example groundbed design in:

- Peabody's Control of Pipeline Corrosion, by A. W. Peabody, 2nd Edition Edited by Ronald L. Bianchetti, NACE International. (in particular, pages 134-137)

The following are referenced:

- Deep Anode Systems, by T.H. Lewis, Loresco, 1997 (see Chapter 6 Resistance Determination pp 93-104)
- Anotec Excel worksheet: SundeDwight04 (Internal document Engineer/Groundbed)

Background:

Before a ground bed is constructed it is necessary to estimate its resistance in order to establish a design that will work effectively (rectifier capacity), and to procure components.

The equations presented by Peabody and by Lewis can be used to estimate ground bed resistance. They are based on engineering that has been proven to be reasonably accurate; so long as values of electrical properties for the system, which are measured or assumed from experience, are appropriate.

According to Lewis, the equations were developed respectively by (1) Dwight, (2) Sunde, and (3) Baechmann and Schwenck. Lewis points out that the 3 approaches estimate results within 10% of each other for the conditions illustrated in his book.

For this analysis One of Dwight's equations was used to analyze how changes in the diameter of the anode (not the length) affect ***Internal Coke Resistance***.

For purposes of this analysis, and for clarity, we define ***Internal Coke Resistance*** Ri as the resistance within the coke breeze between (a) the surface of the anode and (b) the coke-to-earth surface. Lewis refers to this component of total system resistance as "*anode contact resistance to coke breeze backfill*." Ri is calculated in three steps.

1. Calculate the resistance (Ra) of the anode-to-coke, as if the earth is coke.
2. Calculate the resistance (Rc) of the coke column-to-earth, as if the earth is coke
3. Calculate the internal coke resistance Ri = Ra – Rc

By calculating Ri for two or more diameters of anode, the effect of diameter change on Internal Coke Resistance can be readily investigated

The essential questions are:

1. How significant is Ri in comparison to the Total Circuit Resistance of the CP System, or to some other resistance that is meaningful to the reader?
2. What cost is associated with the increased resistance due to anode diameter reduction?

Naturally, if Ri is negligible, Question 2 becomes irrelevant.

Table 1 shows that for a 5 ft anode in an 8" x 7ft column of 5 ohm-cm coke, the increase in internal resistance caused by a diameter decrease from 3.8” to 2.9” is negligible.

Table 1: Increase in ohms when the diameter of a 5 ft anode is reduced from 3.8” to 2.9”.

Increase in ohms for a single vertical anode	0.014 ohms
Increase in ohms for a groundbed of 12 anodes spaced 20ft apart	0.0012 ohms
Equivalent feet of #8 cable (0.654 ohms/ 1000ft)	**1.8 ft of #8**

The results tabulated in Table 1 were derived from Table 2 on page 3.

Table 2 summarizes in some detail how an appropriate formula derived by Dwight [(L69)] was applied, in accordance with Peabody's example ground bed design calculation on pp 134-137.For purposes of this article. this example is presumed to be reasonably representative of normal situations.
Peabody’s example ground bed comprises:

12 cast iron anodes 2” x 5ft, in vertical surface columns of 50 ohm cm coke breeze 8” dia x 7ft deep, spaced 20 ft apart, in a horizontal line.

Peabody calculates internal to coke resistance for a single 2" anode as 0.106 ohms. Some readers may find it difficult to follow Peabody's logic in the text (as did this reader over several attempts before clarity was reached). In fact, Peabody's 0.106 ohms = Ra (anode to "world as coke" = 0.2331 ohms) - Rc (coke column to "world as coke" = 0.1275 ohms), from Peabody equation (1) p 133:

$$R = 0.00521*(p/L)*(2.3\log(8*L/d)-1)$$ for p 50 ohm-cm, and both L and d feet.

Conclusion: A modest reduction in diameter of an anode, with weight and length maintained, should not materially affect ground bed life and performance. This realization led Anotec to develop New Z-Series Tubular Anodes based on reduced diameters relative to traditional norms.

TABLE 2: Calculation of Resistance Change when Anode diameter is decreased from 3.8" to 2.9" for a 5ft length:

Source Reference: InternalOhmsB (Excel worksheet) Rev 0.4 22-Nov-05

Peabody p134: Dwight's equation for a single vertical anode	R =	[0.00521*(p/L)]*[ln({8*L}/{d/12})-1], letting Q = [0.00521*(p/L)] and K = ln({8*L}/{d/12}
	L =	length of anode in feet
	D =	diameter of anode in inches
	ln =	log e =2.3*log10

The following calculation is based on an example calculation on pages 134 to 137 in particular. 12 vertical anodes in coke columns, spaced horizontally in a line at 20 ft centers.

For coke anode 8" x 7ft.	p =	50	ohm cm			Check work
	Lc =	7	ft			84
	Dc =	8	in	Q =	K =	4.4258
	Rc =	**0.1275**	**OHMS =**	0.0372	x (K-1) =	3.4258
For 2in x 5ft anode in coke (this entry is to reconcile with Peabody)	Lc =	5	ft			240
	Dc =	2	in			5.4745
	Ra2.0 =	**0.2331**	**OHMS =**	0.0521	x	4.4745
For 2.9in x 5ft anode in coke	Lc =	5	ft			165.52
	Dc =	2.9	in			5.1033
	Ra2.9 =	**0.2138**	**OHMS =**	0.0521	x	4.1033
For 3.8in x 5ft anode in coke	Lc =	5	ft			126.32
	Dc =	3.8	in			4.8334
	Ra3.8 =	**0.1997**	**OHMS =**	0.0521	x	3.8334
Internal to coke resistance, 2.9in anode	**Ri2.9 =**	Ra2.9-Rc =		**0.0863**	**OHMS**	
Internal to coke resistance, 3.8in anode	**Ri3.8 =**	Ra3.8-Rc=		**0.0722**	**OHMS**	
Increase in resistance 2.9in dia vs. 3.8 in dia	**dRi=**	**Ri2.9 - Ri3.8 =**		0.0141	**OHMS**	
for 12 anode ground bed		**dRi/12 =**		**0.0012**	**OHMS**	
Equivalent Length of #8 Cable (0.65 ohms per 1000ft) **Equivalent to the increase in resistance due to anode diameter decrease from 3.8" to 2.9"**				**~ 1.8 ft # 8 AWG**		

These results are published in Table 1.