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CORROSIVE ACTION OF SOILS ON IRON AND LEAD

A Thesis submitted to

the Faculty of the Graduate School of the

University of Minnesota

by

Laurence A. Stenger

in partial fulfillment of the requirements for the

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CORROSIVE ACTION OF SOILS ON IRON AND LEAD

One of the features of industrial conditions little
noticed by the average person is the multiplicity of pipe
lines, cables, conduits and various other metallic structures
found in the subsoils of cities.   These structures, with
the exception of earthenware sewers and conduits and bitu-
minized fiber conduits, are all constructed from iron, cast,
wrought, pure ingot iron, steel and lead.   The irons and
lead are used for water pipes, irons for electrical conduits
and gas pipes, lead is used as a protective covering for
electric power and telephone cables, usually containing two
per cent of tin.   Rails of street railways may be included
with these structures, also steel foundations of buildings
and steel tunnel linings.

Usually these pipes, etc., are placed in the soil
with the idea they will not be affected, at least to the
point of destruction, by any corrosive agencies.   Attempts
are sometimes made to paint or coat the metallic surfaces
for protection, more often not.

An enormous amount of work has been done investigating
the causes of corrosion of iron and lead in air and methods
for their adequate protection. Comparatively little has been
done investigating and preventing corrosion of these metals
in soils.

There have been several theories advanced to explain
the corrosion of iron[1]. These are the electrolytic[2], the
carbon dioxide or acid, the hydrogen peroxide, the oxidation
and the biological or bacterial. From the results of work
on this subject, together with a study of the writings of
Whitney, Cushman, Gardner[3], Walker[4], and many others on
corrosion in general, it is believed that practically all
corrosion, of both iron and lead, is electrolytic in action.

The general study of the subject was begun with field
observations of underground structures in different places.
Extensive work of this type was done at Havana, Cuba, in 1911,
by Mr. S. T. Dodd and the writer. At that time a new sewer
system was being installed, the excavations for which offered
a rare opportunity for observing the many piping systems
buried in the ground. There it was found the corrosive
action of the soil on iron was severe. The most damage was
done to the smaller iron gas and water service pipes.
From reliable information from several sources, it was found
their life was from three to seven years, for either wrought
iron or steel pipes. A poorly galvanized pipe would corrode
as badly as a black pipe. A good heavy galvanized coat
was an effective protection. Corrosive action was very

(1) Friend, Corrosion of Iron and Steel, p. 34.
(2) Whitney, Jour. Amer. Chem. Soc., 1903, 25, 394.
(3) Cushman and Gardner, Corrosion and Preservation of Iron
    and Steel.
(4) Electrolytic Theory of the Corrosion of Iron and Steel and
    its Application. Jour. Iron and Steel Inst., 1909, 79, p.69.

marked also on cast iron pipe. Careful work was done to find leakage electric currents where this corrosion occurred. None were found. The street railway rails carry no current, the double trolley system being in use. The rails of two electric lines entering the city carried current, these were the only sources of leakage current in the city, and, owing to the good soil conductivity, damage from that current would be localized closely to the lower potential points of the tracks. No damage had been reported from this cause. Furthermore, corrosion had been common in that city before electricity had been used at all, therefore it is absolutely certain the pipes were corroded by reactions between soil constituents and the metal.

In Indiana, there was laid in 1891 an eight inch steel gas pipe with screwed wrought iron couplings. This pipe extended from the Grant County gas fields to Crawfordsville, where it ended about one-half mile from an electric railway. This pipe was taken up in 1911. It was corroded in local areas over the pipe, many places through the walls, and generally over the whole length of line. It was buried three to five feet deep, lying in moist yellow clay soil. This corrosion was also due to reactions between soil constituents and iron and none other.

In Pierre, South Dakota, cast iron water pipes have been replaced account of damage due to soil corrosion only. No source of direct current leakage is in the city.

Small iron service pipes were corroded to leakage in six years. The soil there is a clay and gumbo, it is popularly termed alkaline.

Cast iron and steel pipes have been found in Minneapolis and St. Paul, corroded to destruction in black peat soil, cinder fills and clay. The soils were found to be actively corrosive.

Commercial lead is very long lived under ordinary circumstances. In Havana it was found that lead covers of insulated electric cables laid in earthenware conduits were destroyed in three years. This occurred where running water was in the conduits and only indirectly was caused by soil action. The lead water service pipes buried in clay were in an excellent state of preservation, all observations and information indicated there was no damage done to them.

Consideration of these facts and others leads to the classification of corrosive effects in two types. One, called electrolysis, is the resultant of an outside generated electrical current flowing from the metal by an electrolytic conduction path. The other has been termed auto-electrolysis, it is electro-chemical in nature — nearly all corrosive effects on subsoil structures, not caused from electrolysis, are produced by it.

These two types are to be clearly differentiated, although it has been found their effects are similar.

Electrolysis from leakage currents [6] from the rails
of electric lines manifested itself by corroding underground
pipes in the early days of electric traction development.
At that time, little attention was paid to track bonding and
methods of conducting the electric currents from the rails.
These points, together with other factors tending to reduce
the leakage current flow, have been carefully studied, whence
electrolysis has been/to almost a negligible amount.   It
          reduced
might be expected the rails would be quickly destroyed, as
leakage currents tend to leave them at the higher potential
points, where they are in contact with the soil, which usually
is an electrolytic conductor.   If it were dry, the leakage
current would be reduced to zero, the rail would be insulated.
In practice, it is not found necessary to remove rails because
of electrolysis, it is insignificant.   Usually a small local
area of rail base edge just under the spike head is corroded,
and spikes in wet ties will be sharpened.   This is especially
noted in zinc chloride treated ties, which should not be used,
as they lessen the effective resistance to leakage currents.
The electric current leaving other underground structures is
a small fraction of that leaving the rails, so corrosion
caused exclusively by leakage is small in amount[7].

If an underground structure is discharging a leakage
current, it will be at a considerably higher potential than the

(6) McCullom and Logan, Leakage of Currents from Electric
      Railways, Bureau of Standards Bul. 63, 1916.
(7) J.G. and R.G.Cunliffe, Jour.Proc.Institution of Elect.
      Engrs., Vol. 43, part 197, 1909.

immediately surrounding ground, even if the current density is very small, due to the counter electromotive forces[8] set up at the iron surface, contact resistance, reduced area of soil in the near vicinity of the metal, and the usually quite high specific resistance of the ground. If this electromotive force with structure positive to the ground is found to exceed one volt, with unidirectional fluctuating values, and variable current is found flowing in the structure, with opportunity to leave it through electrolytic conducting soil for a lower potential metallic structure in the near vicinity, electrolysis may occur from the railway leakage current.

On account of the number of variable factors found affecting corrosion rates, among them some that may be called factors of indefiniteness, it becomes rather difficult to isolate factors and study them effectively. Considering the metal alone, the factors affecting its corrosion rates are constitution, properties of components, segregations, foreign substances including gases, states of strain, solution tension and conditions of surface.

External factors, involving the soils and caditions outside of and in contact with the metal are moisture content, gases, composition, electrical conductivity and components. The latter may be chemically corrosive, electronegative to the metal and catalytic in action. Also, porosity or density, homogeneity, concentrations, bacterial conditions, temperature and pressure are to be included.

(8) Irving Langmuir, The Relation Between Polarization and the Corrosion of Iron by Stray Currents. Stevens Institute Indicator, Oct., 1907.

Soils, embodying the external factors of corrosion,
are mixtures of more or less inert solids, colloids and
electrolytes in varying concentrations.   Electrical conduction,
as before mentioned, in soils would in most cases be electrolytic,
as the dry soil is an insulator.

At the beginning of the laboratory work some experiments
were carried out, electrolyzing cast iron and sheet steel in
solutions.   Results of some of these are given on charts accom-
panying.   They show that the iron goes into solution at a
rate of 1.042 grams per ampere hour, approximately.   This is
with a valence of two.   Then further work was done using various
irons in different soils, to compare all effects under the
various conditions, and to find the corrosion rates both by
electrolysis and auto-electrolysis.   Results of some of these
experiments are tabulated.

For getting the data of Table I., the following procedure
was used: Each kind of soil was air dried, crushed and sieved
through an eight-mesh screen.   The moisture was determined,
then pure water added to make up the percentage shown.   The
soils were packed into 250 c.c. beakers.   The electrodes
were No. 22 mild steel sheet, analysis 4, cut 1 x 2.25 inches,
well cleaned, each stamped with a number and a copper wire
terminal soldered to one corner.   One electrode per cell was
dried and weighed, it was to be the anode.   The soldered
joint was covered with paraffine, a rubber tube slipped over
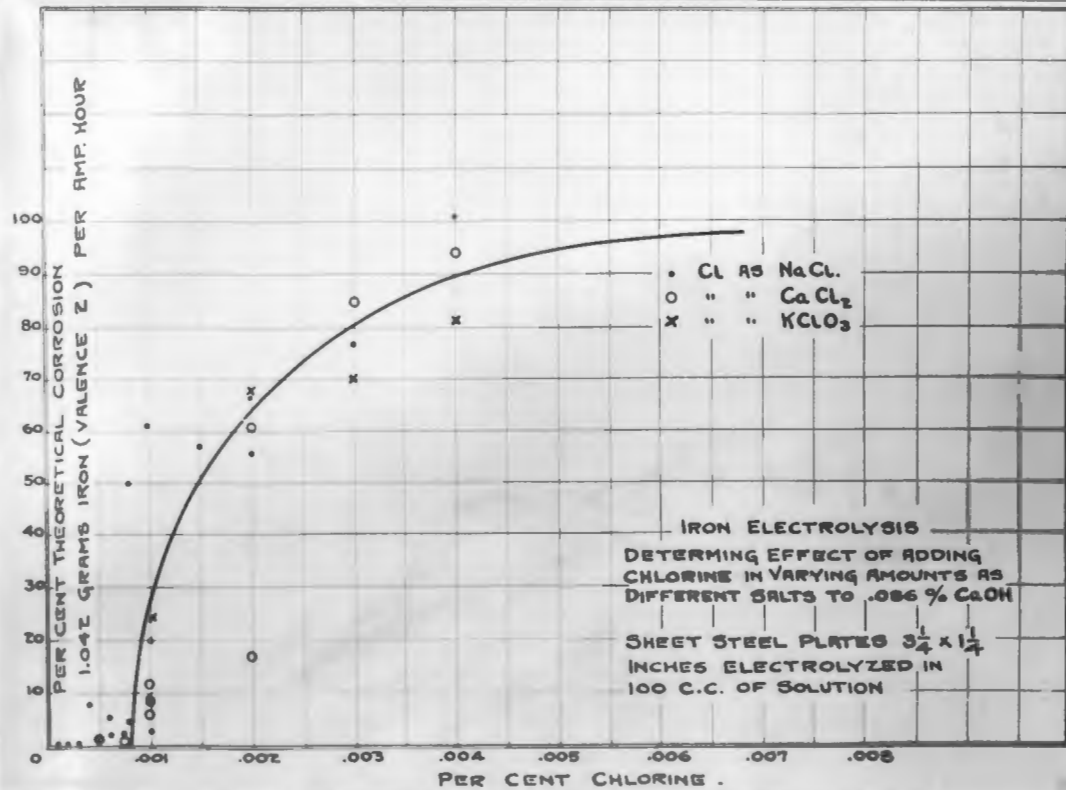the copper terminal, and two electrodes were wet in distilled
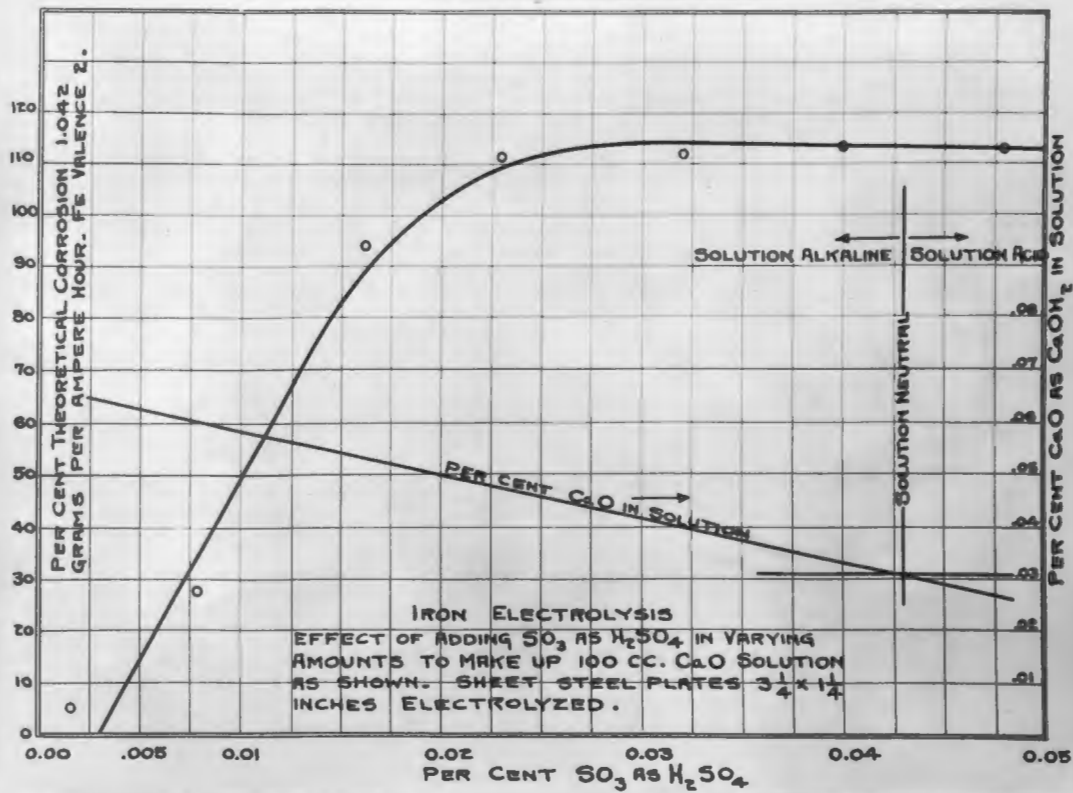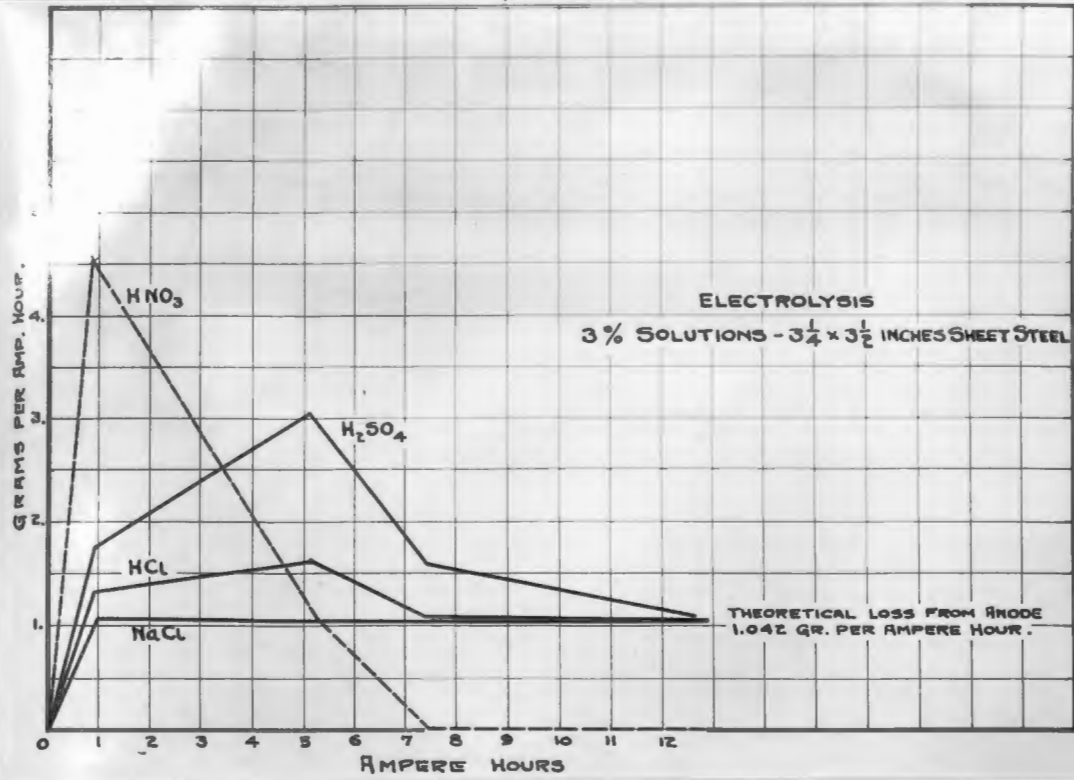
Chart 1

Chart 2

ELECTROLYSIS

3% SOLUTIONS - $3\frac{1}{4}$ x $3\frac{1}{2}$ INCHES SHEET STEEL

HNO₃

H₂SO₄

HCL

NaCl

THEORETICAL LOSS FROM ANODE
1.042 GR. PER AMPERE HOUR.

GRAMS PER AMP. HOUR.

AMPERE HOURS

Chart 3

IRON ELECTROLYSIS
SHOWING IMPRESSED VOLTS COUNTER
VOLTS AND AMPERES - CAST IRON
ELECTRODES $\frac{1}{2}$" x 10 x 14 - 6" APART
IN CINDERS.

AMPERES
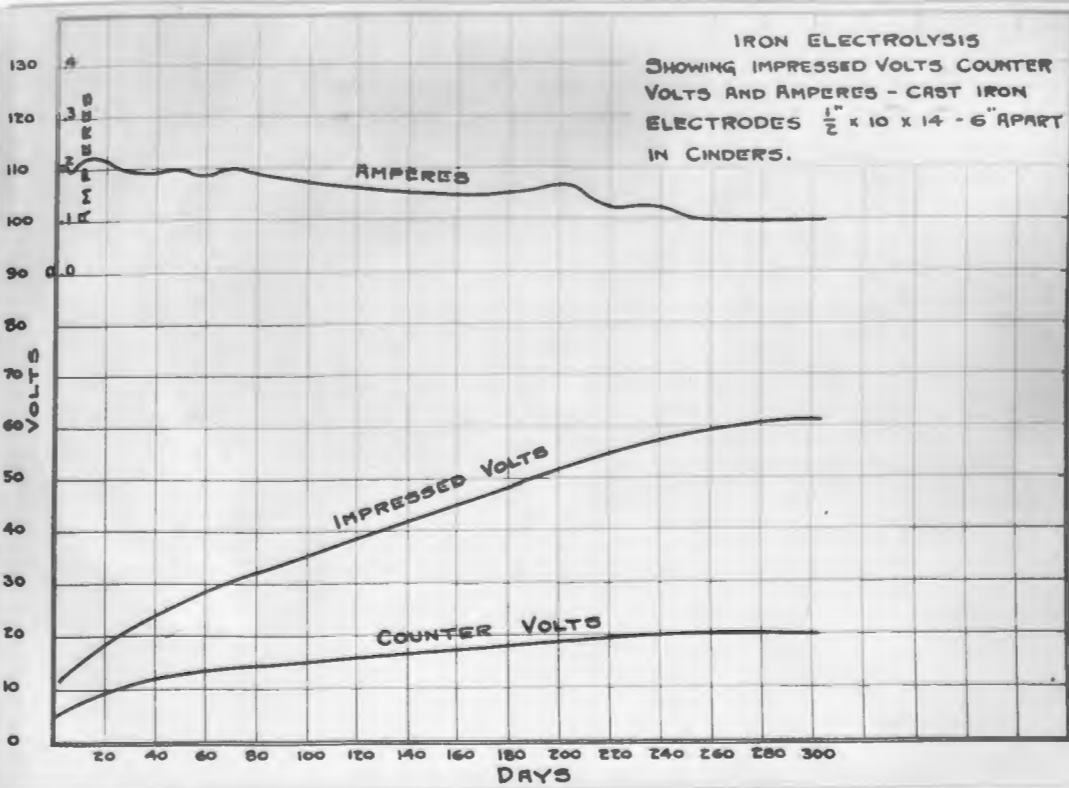
VOLTS

IMPRESSED VOLTS

COUNTER VOLTS

DAYS

Chart 4

water and placed in each cell, about one inch apart.   Each
cell was weighed for the purpose of detecting moisture loss
during the course of the experiment. If any was observed upon
reweighing after several days, it was restored by the addition
of pure water.   Each cell was then placed on a 0.75 x 2 inch
flat cork in a 700 c.c. beaker containing some water and a
strip of filter paper up the inside to keep the air moist.
A watch glass cover was put on.   The cells were allowed to
stand at room temperature for 550 hours, no terminal connected.
Anodes were then removed, brushed clean, rubber tubing and
paraffine taken off, dried and weighed, to get the natural
corrosion.   They were then replaced in the cell, and all
cells were connected in series with copper coulometers and
milliammeter, and constant current of .000233 ampere passed
for 550 hours.   The anodes were then removed, cleaned, dried
and weighed as before.

The corrosion to be charged to the electric current
is the total loss from an anode less its natural loss in the
same time without outside generated current.   The efficiency
of electrolysis then is, in per cent,

$$\frac{\text{grams total loss} - \text{natural loss} \times 100}{1.042 \times \text{ampere hours}} \quad (9)$$

In this work, care was used in all points, especially

(9) McCullom and Logan, Electrolytic Corrosion of Iron in Soils.
     Bureau Standards Bul. 25, 1913.

TABLE I. ELECTROLYSIS

Kind of soil	% Water in soil	Grams loss natural	Total loss under Elect.	Difference	Eff'y. of Elect.	Volts on Cell
	8.3	.001	.033	.032	24	1.3
	12.0	.0007	.1470	.146	110	0.7
Yellow	16.2	.0692	.2097	.140	105	0.45
clay	20.0	.1007	.2095	.160	120	0.4
	26.6	.1192	.2797	.160	120	0.34
	29.5	.1953	.2350	.042	32	0.25
	32.4	.2550	.2245	-.030		0.05
	17.9	.0540	.1593	.1053	79	0.6
Blue	22.6	.102	.1803	.0783	58	0.5
clay	26.9	.166	.2368	.0708	52	0.5
	32.2	.1238	.1907	.0669	50	0.3
	9.5	.00	.0530	.0530	40	0.7
Blue	16.0	.00	.0372	.0372	28	0.6
clay	27.6	.1712	.1638	-.0074		0.55
flaky	36.3	.2699	.2443	-.0256		0.53
Yellow	16.7	.0012	.2443	+.2431	180	0.41
clay	38.0	.0403	.2047	.1644	123	0.01
Black	68.0	.249	.3728	.1238	93	0.06
peat	77.0	.303	.3165	.0135	10	0.10

TABLE II. ELECTROLYSIS

Electrolysis of cast iron anode placed between two sheet steel cathodes in cells similar to those of table I. Duplicate cells without current used to determine natural corrosion loss. Amperes .001, run 1800 hours, 1.8 ampere hours.

Soil	% Water	Grams Natural loss	Total Loss	Efficiency of Electrolysis	Voltage on cells end of test
	14	.454	1.013	31	1.7
Yellow	17	.851	2.485	90	1.5
clay	23	.558	2.274	91	0.7
A.	29	.203	1.039	46	0.9
	31	.231	1.868	90	0.7
	15	1.162	2.461	71	2.0
Havana	22	1.236	2,615	76	0.4
clay	29	.698	2,157	80	0.2
	35	.305	1.9055	88	0.3

Cells same type, placed on variable voltage, taken from a railway return circuit, 0.7 ampere hour.

Soil	% Water	Natural loss	Total Loss	Efficiency	Volts at .001 amp.
	14	.454	.7380	40.6	2.1
Yellow	17	.851	1.303	44	1.2
clay	23	.558	1.350	99	0.4
A.	29	.203	.989	98	0.2
	31	.231	1.099	109	0.55

TABLE III. ELECTROLYSIS

Soils in natural condition as taken from earth, two cleaned plates placed one-eight inch apart in soil, cells as before. Plates marked + and·— were electrolyzed as anode and cathode, electrolyzed cells in series, .000324 amperes adjusted daily to constancy, 646 hour run, 0.209 ampere hour. Remaining cells not connected electrically, plates subject to natural corrosion only. Figures given for all data involved.

Clean gray colloidal clay from 40th St. & Blaisdell Ave.,Minneapolis

Pure Ingot Sheet #16 1.3 x 2.5 inches.		Mild Sheet Steel #22 Analysis 4. 1.3 x 2.5 inches.	
	Grams		Grams
No. 1 +	24.9123	+ 11	13.2436
	24.5795		12.9035
	0.3337		0.3401
2 –	25.6720	– 12	13.5755
	25.6350		13.4850
	0.0370		0.0905
5.	23.6920	15.	12.7650
	23.5471		12.6122
	0.1449		0.1528
6.	25.3750	16.	12.9608
	25.1880		12.8047
	0.1870		0.1561

Black Peat from near Lake Harriet, Minneapolis, Analysis C.

+ 3	25.3740	+ 13	13.4216
	24.9575		12.9815
	0.4165		0.4401
– 4	25.3215	– 14	13.5450
	25.2967		13.4997
	0.0248		0.0453
7.	24.4678	17.	12.2483
	24.3700		11.9620
	0.1178		0.2863
8.	24.5292	18.	13.0097
	24.4272		12.6788
	0.1020		0.3309

TABLE III. A.

Electrical data on cells of table III. Voltage and counter voltage of cells measured with the Lippman electrometer. The counter voltage is read when electrolyzing current is interrupted momentarily.

Cell No.	+ 1 - 2		+ 3 - 4		+ 11 - 12		+ 13 - 14	
Age of cell, hours	Volts	C.V.	V.	C.V.	V.	C.V.	V.	C.V.
0.0 +	.19	−	.03	−	.23	−	.21	−
24	.15		.03		.25		.20	
72	.18		.07	.02	.27		.22	.07
240	.09		.30	.20	.30	.10	.35	.15
408	.08	.05	.27	.17	.40	.18	.50	.25
646	.30	.20	.60	.35	.75	.25	.80+	.40
Efficiency of electrolysis %	77		140		85		60	

ELECTROLYSIS TABLE IV.

Shows losses from electrolysis and auto electrolysis for metals and soils specified.   Treated 556 hours, amperes .000439, 0.244 ampere hours.

	Soils	Clay A	Sand	Peat D
	Per cent water	21.5	8.78	51.3
		.3222	.4463	.6473
Cast		.0810	.3153	.3935
Iron		.2412	.1310	.2538
	Efficiency			
	% electrolysis	95	51.6	100
		.3010	.3582	.4628
Sheet steel		.06	.2286	.2282
with scale		.2410	.1296	.2346
	Efficiency	95	51.6	92.5
		.7745	1.0920	1.1237
Commercial		.0348	.0013	.0234
sheet lead		.7397	1.0907	1.1003
	Efficiency	88	130	131
		.6894	1.3108	1.1485
Lead cable		.0178	.0280	0613
cover		.6716	1.2828	1,0872
	Efficiency	80	152.5	129.5

in measuring the small currents, and in cleaning and weighing the electrodes. Several sets were run, using different soils, and electrodes of lead and various irons and steels with scaled, smooth, and cast iron skin surfaces, with various voltages and current strengths. From all results about 66 per cent of the iron anodes, with electrolysis corrosion efficiency under 100 per cent, gave an average of 81 per cent efficiency. The remaining 33 per cent of anodes at 100 per cent efficiency and over, gave an average of 110 per cent. Lead anodes gave an efficiency of from 80 to 150 per cent. From these results no law connecting any of the variable factors with a definite electrolysis efficiency is noted.

Electrical or galvanic phenomena found in connection with auto-electrolysis were studied. Two identical electrodes of copper (platinum could have also been used) were made, and covered with pads of cotton cloth or filter paper. These terminals were connected to a suitable electrometer. Wetting the pads with dilute acid and placing them on an iron surface, an electromotive force was produced. The resulting current was caused by the iron ions passing into solution at a faster rate in one electrolyte than in the other. The effect is also observed after using soil under the terminals instead of pure acid electrolyte. The energy generated is dependent on various factors, the voltage is due primarily to the solution tension of the metal. Its amount is determined exactly as in primary cells, by the algebraic sums of the contact potentials at the

positive and negative terminals. Studies of these potentials
and the resulting current strengths have been made. A Weston
15 volt voltmeter is a suitable instrument to use for measure-
ment of voltage with electrodes as described about one inch
in diameter. This instrument does not indicate the true voltage,
on account of the limited current flow, but by using a potentio-
meter, it could be found. A special inclined capillary
Lippman electrometer was constructed for this work and found
excellent. It takes no current and indicates potential up
to 0.8 volt accurately. A Weston milliammeter may be used
to measure the current. In making such electrical surveys
on bright pure iron, usually the electrode put down first is
found to be electropositive. The current flow would be
from the iron under it. Using ordinary moist clay as
electrolyte and two similar copper terminals, placing one
clay first on pure bright iron, and in a few seconds the
other in another place on the same piece of iron, closing
the circuit with the copper terminals through the Lippman
electrometer, voltage up to 0.1 was indicated. The copper
terminals may be reversed, also reversing the electrometer,
to determine if there is any voltage due to dissimilarlity
between them — there should be none. Care should be used
to avoid contact between terminals and iron.

With this method, using moist soils as electrolytes,
potentials were measured between points on many kinds and
conditions of irons found in commercial use. On clean ordinary

surfaces, would be found 0 to 0.1 volt, clean iron to mill scale
0.3 to 0.5, clean iron to copper 0.8 to 1.0, clean iron to
carbon 0.8 to 1.0, clean iron to red rust 0.3 volt. The
clean iron would be electropositive in all cases, current
would leave it and cause corrosion.

The destructive effects of auto-electrolysis depend
upon the electronegative material to a considerable degree.
If it is copper, with a flaw exposing iron, under auto
electrolytic conditions a hole will be drilled in the iron in
a surprisingly short time. A superficial corrosion will
expose the graphite carbon in cast iron, a point is made
electronegative and the iron ions are removed through the
porous electrolyte-saturated soft material, characteristic
of corroded cast iron. Mill scale, if thick and unbroken,
is a good protection to iron, but if broken, becomes a source
of danger, it is electronegative. There is a saving feature
that explains why black iron pipes last as well as they do.
As action proceeds, the mill scale is slowly reduced to metallic
iron by the H. ions that may be uncombined for the moment and
the area of corrosion is spread. In soils where the electro-
lytic conditions are not favorable, as in clean sand, action
may be suspended indefinitely, only a small amount of rust
forming.

Localized corrosive action on iron, commonly called
pitting, is destructive for iron pipes, as a leak is caused
in comparatively short time. Pitting may be caused by action

AUTO—ELECTROLYSIS TABLE V.

Iron lost from corrosive action of natural soils. Column A, grams per year lost from plates; column B, grams lost per year per square inch of corroded area. Area of plates 4.8 to 5.5 square inches. Plates underlined treated 1.07 years, all others (except 4" pipe) .23 years.

Soils	CAST IRON As Cast		Polished		MILD STEEL With Mill Scale		Polished		99.94% Ingot Sheet Polished	
	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Clay 21.5% water	2.02	1.18	1.36	0.90	0.83 / 1.17	0.41 / 0.51	.992	0.34	0.47	0.12
Black Peat 39.4% Water	2.75	1.05	3.44	2.65	2.22 / 1.70	2.47 / 0.57	2.82	1.76	2.82	1.47
Mixed 27.8% Water	1.48 / 1.34	1.18 / 0.64	2.41	1.60	1.29 / 0.84 / 1.06	.807 / 0.45 / 0.59	1.69	0.70	1.17	0.47
Loam	1.51	0.66			0.97	0.52				
Clay and Black Peat	171.	5.18	4" cast iron pipe, 41.5" long, treated .85 year.							

AUTO-ELECTROLYSIS TABLE

To determine corrosion rates in soils, using the original and extracted soils and the water solution made as near as possible of the same soluble salt concentration as salts had in original soils.   Armco iron analysis 1, plates 0.55 x 3.0 inches, treated 552 hours.

	Original soil	Extracted soil	Solution
Clay A, % water	17.4	22.0	
Grams iron lost	.0147	.0090	.029
Clay B, % water	26.4	33.6	
	.0207	.0545	.0245
Peat C, % water	82.5	84.0	
	.0238	.0169	.0247
Peat D, % water	45.8	59.0	
	.1208	.0488	.0340

TABLE VII.

A comparison of auto-electrolysis in different soils, using Armco iron analysis 1, 1.3 x 2.5 inch polished plates. Grams iron lost after treating 528 hours in fiber cells. Water content approximately the natural percentage.

Clay A................................... .0198

Dark gray clay, Pierre, So. Dak........... .0613

Yellow clay, Indiana...................... .0915

Light white clay, Havana, Cuba............ .0295

Yellow clay, Havana, Cuba................. .3249

Blue clay, Minneapolis.................... .0597

Peat D................................... .1230

A comparison of auto-electrolysis on sheet irons and steels as specified, treated in fiber cells, clay A, 528 hours. Grams iron lost from 1.3 x 2.5 inch plates.

Armco iron 1, heavy scale................. .0054

"   draw filed.................. .0650

"   polished.................... .0534

Sheet steel 3, irregular scale............ .0808

"   draw filed................. .0702

"   polished................... .1967

around an electronegative particle in contact with the iron.
The + Fe ions leave the iron surface, setting up the current
flow.   The action will continue because the reaction products,
Fe, H, and O ions are removed from the system as such.   In
time, the Fe becomes Fe_2O_3 X H_2O, insoluble, but porous, and
conducting.   O helps to form it.   H ions are removed as H_2O
formed from the OH ions of electrolysis.   If free H_2 were
formed (rapid action) the current would be reduced or stopped
by insulation due to the gas film on the electronegative area.
With the slower action current flow is practically continuous,
whence the corrosion rate is continuous.   This is borne out
both by general observations and experiments.   Table V. shows
corrosion rates approximately the same for different times
specified.

Also, cells were set up with steel in different soils
and electrolytes, so arranged as to collect all evolved gases.
Cleaned mild steel, analysis 4, 1.12 x 4.25 inches, treated
600 hours.   Grams loss from steel in pure water was 0.023,
cinders 0.1687, peat D 0.208, peat C 0.050, clay A 0.0473.
No gas came from these cells.   In $\frac{N}{10}$ H_2SO_4steel loss was
0.700 grams in 120 hours, evolving 314 c.c. of gas.   After
this (solution not renewed) iron loss was 0.0155 grams in
480 hours with no gas.   Whence corrosion in the soil cells
was purely electrolytic, with perfect depolarization, allowing
a continuous corrosion rate.

Pitting will occur in polished, pure irons (analysis 1) in a clean well mixed clay, due to the same causes with no apparent electronegative areas to direct or localize the reaction. This may be due to either or both the following causes, slight differences, in the iron itself, or concentration cells set up in the clay. Using the Lippman electrometer with electrodes of similar metal, preferably small platinum wires, surveys over a piece of moist clay showed potentials of 0.01 to 0.02 volt between different points. Attempts were made in this way to locate the low potential points on a smooth clay surface. Then a polished pure iron plate was placed on it. Allowing action to continue a few days, the iron was examined to see if the corroded areas had any definite relation to these low points. Fair correspondence was obtained on one specimen, but others did not give definite results. These potentials are very difficult to locate, but it is probable they aid in starting local actions on the iron surface, producing red rust in small amount. This is electronegative and action then becomes definite and pitting proceeds.

A different type of corrosion cell was used to duplicate conditions of underground structures for further experiments on auto-electrolysis measurements. Three-inch bituminized fiber conduit was cut in sections about three inches long and filled with soil, in which was placed the iron plate. Sheet rubber disks placed in the ends made them air and moisture

tight, and paraffined wooden disks over these completed the cell. With this arrangement, the specimen could be subjected to pressure. Sets were made up to determine the effects of different pressures and temperatures encountered in practice. These results are found in Table VIII.

Lead, having a very low solution tension, is not so susceptible to auto-electrolysis as is iron. External conditions will produce corrosion, however, in a somewhat different manner. If two soils are in contact with a metal, one of which contains a substance subject to a change of valence[10] we may expect an electrical current flow. This current will enter the metal as part of its circuit, and leave it again, in the near proximity of the bi-electric soil, causing corrosion of the cathode areas[11].

Lead is also liable to corrosion from other conditions. Pipes leaving moist cement floors often corrode near the floor line. Cable covers lying in cement ducts and lead pipes in mortar walls are also destroyed. If water from condensation or other sources is allowed to collect or run down or around a lead structure under conditions when soluble salts are present, there will be formed a concentration cell[12]. The electromotive force set up is caused by different velocities of different ions, which would be found in any surroundings

(10) Jones, Elements of Phys. Chem., p. 476
(11) Scofield and Stenger, Corrosion of Metals in Natural Soils, Elect.Ry.Jour.,1914, p. 1092.
(12) Bigelow, Theoretical and Physical Chemistry, p.478.

AUTO—ELECTROLYSIS TABLE VIII.

Corrosion rates, grams lost from plates in 480 hours.   Pure ingot iron, analysis 1, No. 16 gage, 1.3 x 2.5 inch polished.   The first horizontal row for each soil was at a temperature of 20 to 22 Cent., the second, 14 to 15, the third 8 to 10.   Covers practical external conditions of buried water pipes.

Pressures, Lbs. per sq.in.	0	2.8	5.7	8.6	10
Soil A.	.0075	.0090	.0317	.0102	.0297
Water 16%	.0534	.0063	.0127	.0489	.0243
	.0118	.0608	.0045	.	.0109
Soil	.0307	.0317	.0354	.0352	.0262
Clay B.	.0622	.0574	.0459	.0205	.0867
Water 25%	.0540	.0632	.0499	.0463	.0317
Soil clay	.0128	.0482	.0681	.0201	.0205
Water 16%	.0432	.0445	.0267	.0370	.0367
	.0130	.0623	.0139	.0148	.0354
Soil	.2310	.2678	.2965	.2598	.2411
Peat D.	.1875	.2933	.2418	.2585	.2354
Water 53%	.1710	.2115	.0990	.2068	.2352

Comparing ingot iron 1 and copper bearing steel 7, 0 pressure, 20°–22° Cent.:

Soils	Iron	Cu. Steel
A	.0075	(.0987
		(.1564
B	.0307	
Clay	.0128	.0464
Peat D	.1710	.2673

of a pipe in cement or soil. The more dilute solution would
be the fresh moisture supply, the more concentrated solution
would be near the metal surface in the surrounding medium.
Common specific instances of this type of corrosive action
are seen at the bases of trolley poles at the ground line.
It occurs also if the pole is set in cement. This is a
plausible explanation of the corrosion of the lead cable covers
at Havana, previously mentioned. The bottom side of the cover
lay in detritus, electrolytically more concentrated. The
dilute solution would be from condensation and the intermit-
tently flowing water in the conduit, in contact with the
upper surface of the lead.

ANALYSES OF SOILS.

400 grams of soil were extracted for several weeks, using about 10 l. of water for each sample. The solutions were evaporated and analyzed. Figures given are grams per 1000 grams of soil.

	A Clay	B Clay	C Peat	D Peat
Al_2O_3				.3480
SiO_2	.0146	.1550	.0061	.1181
CaO	.4580	.1515	.1012	.8240
MgO	.2740	tr.	tr.	.1074
SO_3	1.4364	.2600	.1035	5.1130
Ignited) Solids)	2.5000	.850	.3620	8.620
Total) Solids)	2.838	1.175	.6280	13.2480
CaSO4 ppt. on boiling solution				18.2400
				31.4880

Clay A, from street east end Selby Tunnel, St. Paul, 6 ft. depth.

Clay B, from Snelling Av. & Lake St., Minneapolis, 4 ft. depth.

Peat C, from swamp north of Lake Harriet, 4 ft. depth.

Peat D, from Summit & Wabasha, St. Paul, 6 ft. depth.
Also found at location of Clay A.

Resistance of clay A, per cubic centimeter, 23.75 per cent water, at 3.6 Cent., 860 ohms; 15 Cent., 620 ohms; 25 Cent., 484 ohms; 26.1 Cent., 463 ohms.

With 20.56 per cent water, at 26.1 Cent., 527 ohms; 15.25 per cent water, 846 ohms.

Water content soil A, 17.4%; B, 26.4%, C, 82.5%, D, 45.8%.

ANALYSES OF IRONS

No.	1	3	4	5	6	7
				2.20	3.23	
				.73	.41	
C.	.02	.200	.060	2.93	3.64	.153
Si.	.003	.003	tr.	3.070	1.62	
S.	.005	.041	.019	.051	.133	
Mn.	.011	.432	.365	.283	.324	
P.	.000	.010	.027	.500	.458	
Cu.	.000	.170	.000	tr.	tr.	.233

1. Armco pure ingot iron No. 16 sheet.

3. No. 16 sheet.

4. No. 22 sheet.

5. From six inch cast iron pipe.

6. Cast iron, cast in 1/8 x 1 inch strips, broken two inches long, for test in soils.

7. No. 20 sheet, American Sheet & Tin Plate Co.

Conclusions

Electrolysis of underground structures may be caused by certain definite conditions, which may be determined by electrical measurements and a study of the environments.

The electrolytic theory is applicable to corrosion of underground iron and lead structures.

In comparing the corrosive resistance of different types of irons and steels, a careful study of the conditions under which the irons are to be used should be made, and tests conducted under these conditions. One or two tests are not sufficient, several should be carried out.

From experiments performed, and corrosion rates found, the probable life of an iron structure in given soils may be predetermined. The weight of 1/8 inch iron one square inch in area is 15.8 grams. Assuming corrosion forms a conical pit, the metal removed weighs 5.2 grams. From data of table V. the yearly rate of corrosion per square inch is 0.83 grams. $\frac{5.2}{.83}$ is 6.2 years, the approximate life of a mild steel black iron pipe with 1/8 inch wall, in clay A.

A factor showing the tendency of an iron to pit would be the corrosion rate per square inch of corroded area. The cast iron pipe noted in table V. was severely pitted.

The ordinary coatings, mill scale, poor grades of galvanizing, casting skin and tar dips on cast iron have little value as protection against auto-electrolysis, and in cases accelerate it. Tar dips lengthen the life of cast iron by delaying the action, but the coating will soon fail in spots.

The longer life of cast iron is due only to its greater wall thickness, Chart 6, page 17a.

Corrosion rates of iron are little affected by temperature changes within the range usually found about water pipes.

Corrosion rates are appreciably increased by pressures within the range of pressures met in practice due to depths of burial.

Admitting or excluding air from a test cell has no appreciable effect on corrosion rates.

POTENTIAL DROPS FROM CURRENT FLOW
BETWEEN #16 CLEAN PURE IRON ELECTRODES
$1\frac{1}{4} \times 2\frac{1}{2}$ INCHES - 8 INCHES APART IN CLAY A
IN $6 \times 7 \times 10$ INCH BOX.
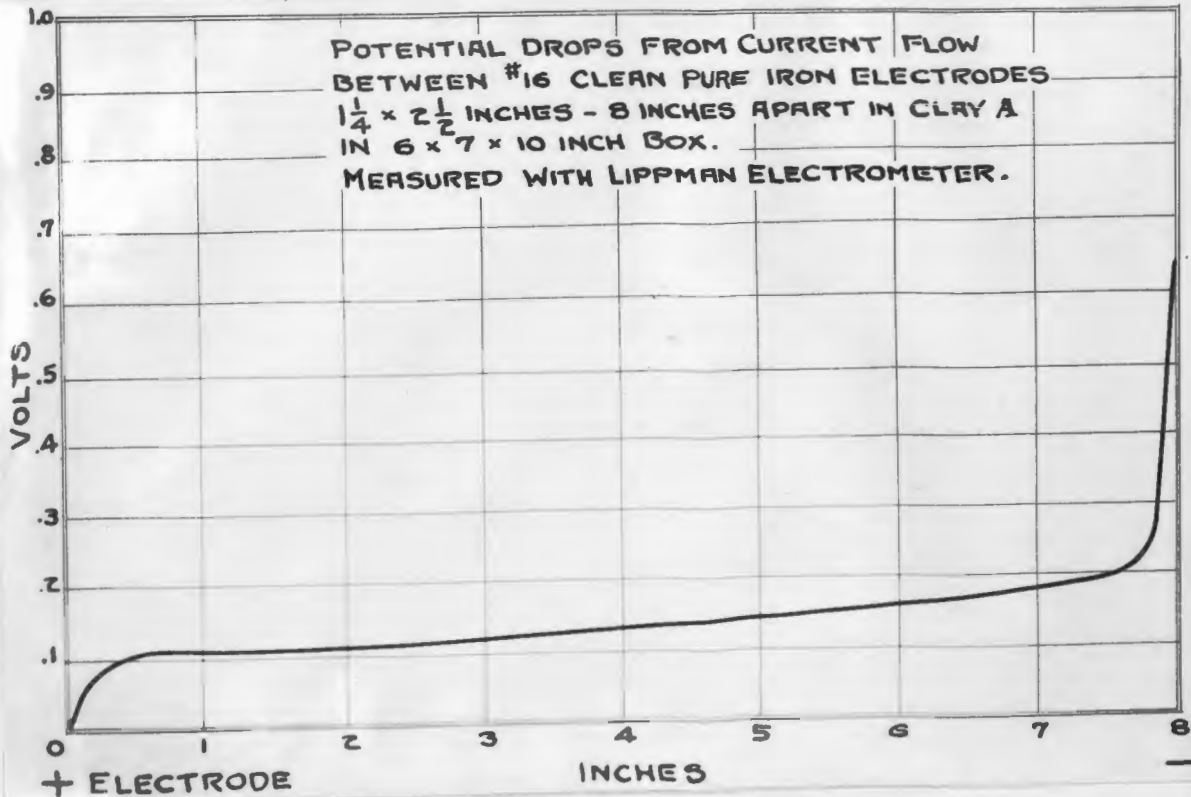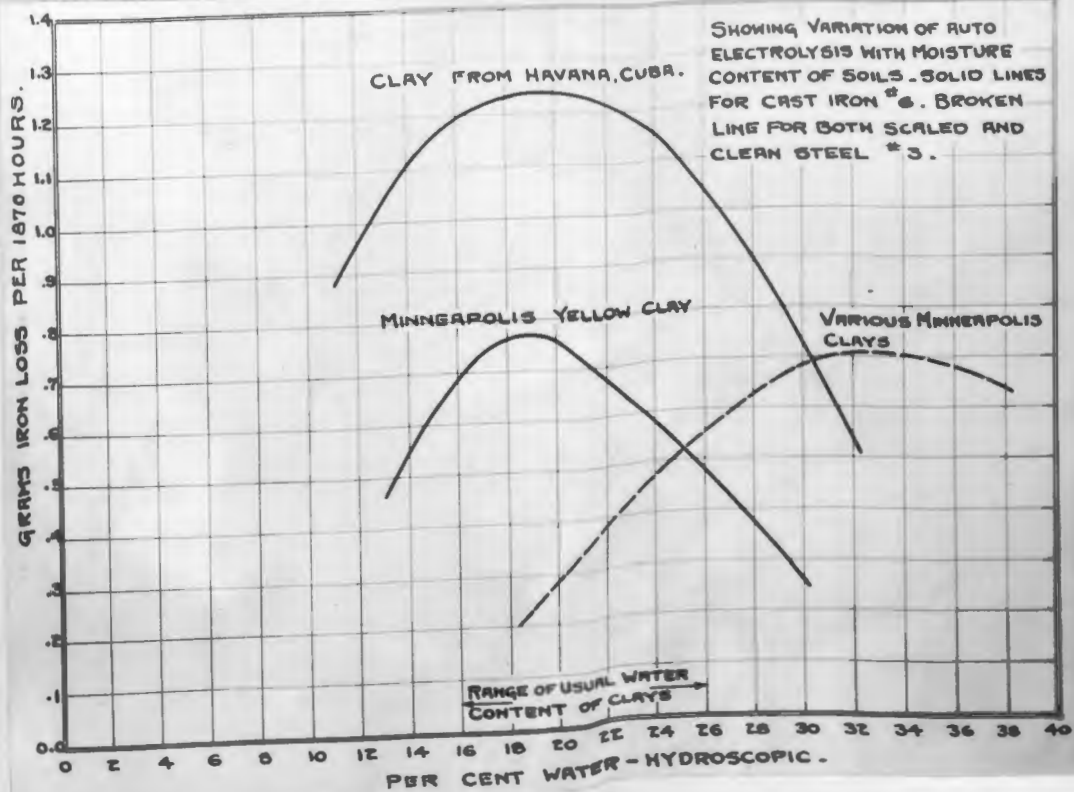MEASURED WITH LIPPMAN ELECTROMETER.

VOLTS

+ ELECTRODE   INCHES   —

Chart 5

SHOWING VARIATION OF AUTO
ELECTROLYSIS WITH MOISTURE
CONTENT OF SOILS - SOLID LINES
FOR CAST IRON #6. BROKEN
LINE FOR BOTH SCALED AND
CLEAN STEEL #3.

CLAY FROM HAVANA, CUBA.

MINNEAPOLIS YELLOW CLAY

VARIOUS MINNEAPOLIS CLAYS

GRAMS IRON LOSS PER 1870 HOURS.

RANGE OF USUAL WATER
CONTENT OF CLAYS

PER CENT WATER - HYDROSCOPIC.

Chart 6

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