PROTECTING OIL RESERVOIRS AGAINST LIGHTNING[1]

By MARION E. DICE

During April, 1926, lightning caused the destruction of 9,000,000 barrels of oil storage facilities in California, with an economic loss second in the history of the State only to that of the San Francisco disaster of 1906.

The catastrophe awakened the petroleum industry to the hazards of above-ground storage and set in motion a number of engineering activities which have led to the general adoption of protective measures throughout the State.

This article is intended to report a survey of methods and to describe the present state of the art of lightning protection as practiced in California. * * *

Lightning protection systems.—Three methods of protection against lightning are in use: (1) Towers which function as lightning rods, (2) networks to prevent sparks caused by induced discharges, and (3) barbed wire designed to discharge the thundercloud sufficiently to prevent dangerous voltages.

A summary of the number of barrels of reservoir storage protected by various means by the major operating companies is given in Table I (not reproduced), which lists 95 per cent of the storage in the State. The remaining 5 per cent is probably in isolated locations and unprotected.

In addition to the reservoir protection listed in Table I, the Associated Oil Co. has installed towers and networks to protect 286,000 barrels of steel tankage with wooden roofs. All-steel gas-tight tanks are believed from experience to be able to carry direct strokes safely.

Table I shows 25,300,000 barrels of storage without protection. Most of these reservoirs are small and in isolated locations far from populous centers and are used only for heavy oil. Protection will probably be installed for some of them before the next thunderstorm season. Some of these reservoirs are emergency containers made by throwing an earth dam across a canyon in rolling country, with no floor covering and no roof. They are used for heavy oil containing much sand.

Dimensions and locations of towers.—The towers are usually of steel lattice construction of the type used for radio antenna supports. They are from 75 to 200 feet high. The base is from 4 to 24 feet square, resting on concrete footings. The upper portion of the tower is usually a piece of pipe, with various kinds of pointed tips.

In some cases the towers are connected by cables fastened to the lattice work below the pipe extensions. One company grounds the center of each cable span by a copper down lead, and places a 7-foot copper rod at the junction of the cable and the down lead, with 3 feet of its length projecting above the cable. This is intended to localize corona and, by forming an ionized path, aid in directing the stroke to the system.

Most of the towers were located in accordance with the experimental findings of F. W. Peek, jr., of the Pittsburgh laboratories of the General Electric Co. ("Lightning; a study of lightning rods and cages, with special reference to the protection of oil tanks," Journal A. I. E. E., 45, 1246, December, 1926). He originally proposed an empirical law that a lightning road would protect a radius equal to four times its height, and five companies built towers on this basis. Later laboratory work, however, brought about a modification of the law and led to an increase in the height of many towers. One company has increased the height of its towers from 150 feet to 200 feet. The new basis, shown in the accompanying chart (Fig. 1), gives the protected radius (in terms of rod heights) as a function of the ratio between the cloud height and the rod height.

Most of the reservoir farm rod layouts were tested by means of scale models in the Pittsfield laboratories, and final installations were made on these results rather than on empirical data from ideal cases. A model of the Southern Pacific Co.'s 3,000,000-barrel reservoir at Tracy was subjected to 2,300 discharges of artificial lightning without a single stroke to the reservoir.

The General Petroleum Corporation made an elaborate series of tests with models at the California Institute of Technology, through the cooperation of Prof. R. W. Sorensen, before drawing up its construction program. The layouts adopted were tested again by Mr. Peek with results in close agreement with those of Pasadena.

The Pan American Petroleum Co. carried out its own laboratory work along somewhat different lines as mentioned later.

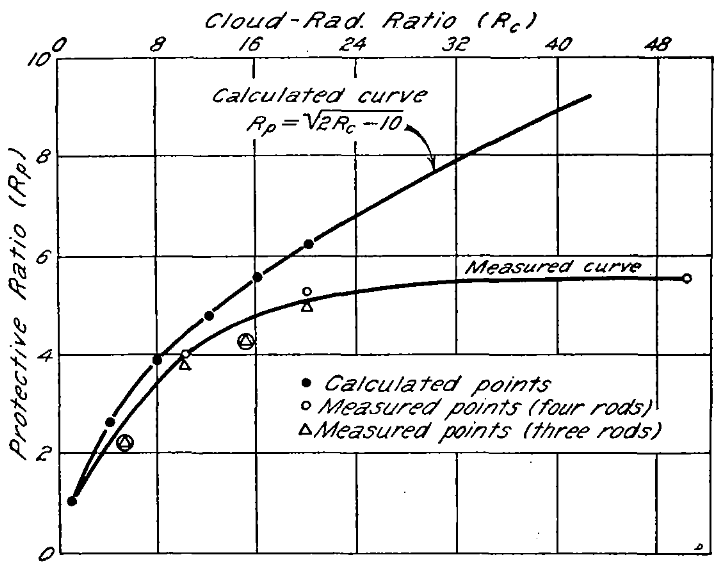
[1] Abstracted from Engineering News-Record of July 7, 1927.

Thundercloud heights.—In order to use Mr. Peek's protective ratio chart, it is necessary to know the approximate cloud height. Weather Bureau observers have measured the altitude at which kites and pilot balloons disappeared into the bases of clouds on 5,500 occasions east of the Rocky Mountains. Thunderclouds were measured in 700 cases.

The lowest thundercloud base measured was 820 feet above the earth. The altitude of maximum frequency was 3,120 feet. Only 6.3 per cent of the cloud bases were below 2,000 feet; 69.6 per cent were between 2,000 and 6,000 feet; and 24.1 per cent were above 6,000 feet.

The height of thundercloud bases varies inversely with the humidity of the rising air. Therefore, since the average humidity on the Pacific coast is lower than in the Central and Eastern States, the range of altitudes given is too low for the Pacific coast. Only in exceptional cases will thundercloud condensation occur below 2,000 feet in California, and 1,000 feet may be set as an absolute minimum.

Ground connections.—The importance of good ground connections is recognized by all companies. Two have drilled a well to permanent water at each tower. Another has wells at most towers and connects the others to pipe lines. Two use pipe grounds driven to moist soil or kept moist by water from within the pipes.



Two make ground connections to pipe lines only. Most companies bond their lightning protection systems to several earth connections; to permanent water, to pipe lines, and in many cases to buried copper rings surrounding the reservoirs.

The General Petroleum Corporation connects each tower to permanent water through a well from 31 to 60 feet deep. A No. 4 copper wire is used, being connected to each leg of the tower, to the pipe casing of the well, and to a weight hung below the water level in the pipe. The pipe is set in steel punchings to increase the area of metal in contact with water and earth. Each tower is also connected to the 3-inch water line surrounding the nearest reservoir. The water line is connected to the reinforcing mesh of the concrete by No. 4 wire at several points around the rim.

Where cables are used between towers, the center of each span is grounded (to decrease the inductance) by a ⅛-inch flexible copper sash cord falling from the cable, anchored to a pipe post just outside the fire wall, and connected to the water line around the reservoir. This system provides metallic paths for ground charges from both their possible levels and the tower system, recognizing that the ground charge may reside at the level of permanent water or at the surface, depending on the conductivity of the earth.

Measurements of resistance indicate values less than 10 ohms through earth paths between separate wells or between wells and pipe lines, and less than 1 ohm through all metallic paths of the system.

Most companies have made no special provision for grounding the reinforcing steel of the reservoirs. The concrete floors are of such large area that good ground contact is assured. Many resistance measurements have been made between the mesh and near-by water pipes. So far as is known, none of the resistances exceeded 10 ohms; most of them were lower.

Network protection.—It is well known that fires may be started by lightning without occurrence of direct hits. A cloud-to-cloud discharge or a stroke to earth at some distance from an oil tank may cause sparks between isolated metal parts due to the release of the bound electrostatic charge.

For example, a thundercloud may have its charge gradually increased, by the breaking up of water drops falling through upward currents of air (Simpson, G. C., "On the electricity of rain and its origin in thunderstorms," Phil. Trans. Roy. Soc. A 209, 379, 1909. See also Proc. Roy. Soc. for April, 1927), or whatever process takes place, until the voltage approaches spark over. During the charging-up period, a charge of opposite sign builds up by induction on the earth below. At spark over (whether to another cloud, to another part of the same cloud, or to earth) the induced charge on the earth is released. It spreads out in all directions to get back to normal density. Sparks can occur during this rush only between isolated conductors or conductors in poor contact. A reservoir roof may have isolated metallic structures such as gauging wells, swing-pipe winch boxes, ventilators, etc., or it may have a combination of metal nailing strips, nails, and patches of condensate below the roofs with dangerous spark gaps.

All reservoir owners have inspected their reservoirs and have taken precautions against such conditions wherever possible. Metallic equipment and pipes have been interconnected and grounded. Roof structures well out from the edge have been grounded by No. 4 or No. 6 copper wires running down through the oil to the reinforcing mesh or over the reservoir bank to a water pipe.

Perfect protection against induced discharges may be obtained only by the use of all-metal roofs, with all joints well bonded. An approximation to an all-metal roof may be secured by the use of wire mesh or networks.

A system developed by Dr. E. R. Schaeffer, of Johns-Manville (Inc.), has been adopted by three Pacific coast companies. It has been placed on 32 reservoirs with a total capacity of 26,250,000 barrels and on a number of wooden-roof steel tanks. This method uses the electrostatic shielding effect of a system of grounded wires suspended over the roof. It is a development of the Faraday cage, based on the equations of Maxwell and on laboratory and field tests extending over several years.

The network used on reservoir roofs consists of No. 12 galvanized telephone wires, parallel, spaced 4 feet apart and 6 to 12 feet above the roof. The wires are supported by a 3/8-inch peripheral cable carried on posts around the reservoir and by another cable crossing the roof on posts. Where the strength of the roof is not sufficient to carry the additional load, the center cable is suspended from a catenary. The network projects 16 feet beyond the rim at all points.

The network used on wooden roofs of steel tanks consists of an umbrella type grid supported by a single post 9 feet above the peak of the roof and by galvanized brackets spaced 15 feet apart around the rim. No. 12 galvanized wires radiate from the center post to the brackets with supplementary wires filling the wide gaps near the periphery so that the maximum spacing of wires is 5 feet.

On both reservoir and tank grids all wires are carefully bonded to the peripheral cable or tank brackets. The cables are grounded through their radial guys to water pipes or to a copper wire buried 12 inches and surrounding the reservoir.

The value of the network is due to the fact that it carries the induced charge, keeping if off the roof and affording good metallic paths to ground for its return after release. The percentage of the induced charge removed from the roof to the network is a function of the diameter and spacing of the wires, their height above the roof, and the cloud height. The arrangement adopted is one whichi s claimed to be an economical approximation of an all-metal roof.

Prevention of lightning voltages.—One company has adopted a system which it is claimed will prevent the formation of lightning voltages and therefore prevent both direct and induced discharges. The system consists of barbed wire strung on steel towers 80 to 100 feet high around each reservoir for the purpose of dissipating, by corona discharge, any induced charges in the area. The inventor, John M. Cage, of Los Angeles, claims that the charge of a thundercloud may be neutralized in this manner or kept below the sparking value. This system, which is described in detail in current petroleum journals (Wilcox, E. H., "Lightning protection system adopted to prevent, not guide, the stroke," Nat. Pet News, March 9, 1927, p. 77; same author, "The cage system of lightning protection," Oil Age, March, 1927, p. 18), has been installed on six reservoirs with a total capacity of 12,500,000 barrels. Included in this group is the largest oil reservoir in the world. The reservoirs are used for fuel oil only.

A COMPARISON OF AIR AND SOIL TEMPERATURES

By HARRY G. CARTER, Meteorologist

[Weather Bureau, Lincoln, Nebr.]

During the five years 1900 to 1904 a record was kept of the temperatures of the soil at depths of 1 inch, 3, 6, 9, 12, 24, and 36 inches at the Agricultural College of the University of Nebraska, at Lincoln. The thermometers were read once daily, at about dark. The data were tabulated and comparisons made with air temperatures as recorded by the United States Weather Bureau at the regular 6:45 p. m. observation at the city campus of the university, about 3 miles to the southwest.

The thermometers used in obtaining soil temperatures were standard soil thermometers. The scales from which the readings were made were made above ground so that the thermometers were not disturbed when read. The tube of each was inclosed in a closely fitting wooden cylinder which prevented air from passing down around it and also prevented the mercury in the tube from being affected by the surrounding soil. The bulb at the bottom was uncovered. The surface of the ground above the thermometer bulbs was kept free of grass and weeds over a rod square. The readings were made daily just before dark.

It was found that the temperature, for the year as a whole, averaged 54.9° in the air, and 58.2° in the soil at a depth of 1 inch. There was a decrease in annual temperature of the soil from 1 inch down to 12 inches, where it averaged 51.5°, then a slight increase down to 24 inches, where it averaged 52.2°. The average at 36 inches was the same as at 24 inches. For the whole year the temperature of the soil at a depth somewhere between 6 and 9 inches averaged the same as the temperature of the air.

Table 1 gives the mean monthly and annual temperatures of the air and of the soil at the various depths at which readings were made.

TABLE 1.—*Mean monthly and annual temperature of the air and of the soil at depths of 1 inch, 3, 6, 9, 12, 24, and 36 inches, at Lincoln, Nebr., for the 5 years 1900 to 1904, inclusive, as determined by considering one daily reading of the thermometers*

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Air	29.2	25.1	42.8	56.5	67.8	75.6	82.7	79.1	68.4	60.7	42.5	28.8	54.9
Soil:													
1 inch	30.0	28.2	42.4	58.6	74.5	82.3	90.8	85.6	72.0	60.0	43.5	31.0	58.2
3 inches	30.0	28.7	41.1	59.3	72.1	81.2	88.6	85.3	72.9	61.4	44.3	31.6	58.0
6 inches	29.6	28.0	37.9	54.5	68.7	77.5	83.6	82.0	71.0	60.2	44.1	31.9	55.8
9 inches	30.0	28.4	35.7	50.8	64.4	73.0	79.4	77.9	70.5	59.0	44.3	33.4	53.9
12 inches	31.4	29.3	35.0	48.2	60.8	69.5	75.8	75.0	66.6	58.4	45.1	34.8	51.5
24 inches	35.1	32.9	34.7	44.8	56.5	64.2	70.8	71.6	66.9	59.7	49.5	39.5	52.2
36 inches	38.1	35.3	35.7	43.0	53.2	61.1	67.5	69.4	66.7	60.7	52.1	43.2	52.2

A study of Table 1 shows that the lowest mean monthly temperatures in the soil were recorded at all depths during February, and from 1 inch down to 12 inches the highest monthly means were recorded during July. At 24 and 36 inches there was a slight lag, the highest monthly means being recorded during August instead of July.