Asphyxiation in Street Manholes

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THE DEATH of a plumbing company employee in a water-main manhole in Minneapolis on June 10, 1952, brought to the fore, for a second time in Minnesota, the danger of suffocation in an apparently innocuous manhole.

The manhole where the death occurred is located on a city street in a low, swampy area. The manhole was a new one—it had been completed on May 26, 1952, to provide a water connection for a new building under construction. Irregularly cylindrical in shape, it has a diameter of about 4 feet and a depth of 9 feet, and is constructed of concrete bricks which are sealed together with mortar. It has, like all manholes, an iron ladder built into the wall and a standard iron cover at street level. The center opening in the cover is about 1½ inches in diameter. The manhole contains only a 4-inch gate valve opening from a 6-inch main.

Account of Death

For approximately 2 weeks preceding the death, some employee of the contractor plumbing company had entered the manhole twice a day—in the morning to turn on the water and in the late afternoon to shut it off. The deceased workman had performed this service himself without any mishap on the 2 or 3 days immediately preceding the accident.

On the morning of June 10, another employee of the company had turned on the water and returned to the surface with no evidence of distress. At the end of the afternoon shift, the deceased entered the manhole and turned off the water. When he did not come up in the expected time, his partner on the surface looked down and called to him. There was no reply. He saw his coworker slumped over in a sitting position.

An ambulance was summoned immediately, and efforts were made to bring the man to the surface. After several fruitless attempts, the inert body was finally removed in about 20 minutes. The workman failed to respond to oxygen and artificial respiration and was pronounced dead by the ambulance physician. The coroner's report attributed the cause of death to asphyxiation.

The cover of the manhole was replaced by workmen after the accident and removed again the next day, June 11, to open the watergate which was then left open. Thereafter the cover remained in place until June 16. The floor of the manhole was dry and appeared to consist only of soil and mortar debris.

This death, like the two deaths which occurred in Winona, Minn., on Friday, October 13, 1950, appeared to be from oxygen depletion (*1*). The circumstances of death were similar

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in that the tragedies occurred in manholes which contained no poisonous gases and where the only opportunity for circulation of air was through the covers. Also, both manholes were located in areas which at one time had been low or swampy. The manhole where the death occurred in Minneapolis, however, was dry, whereas the manhole in Winona contained water.

The death was not reported immediately to the Minneapolis Health Department so that there was no opportunity to get air samples from the death trap at the time of the accident. It seemed incredible that a man should die of suffocation in a manhole which had been entered twice a day for 2 weeks and once on the morning of the accident day without anyone showing signs of distress before the tragedy. Interest in the case was aroused, and it was decided to investigate further. The phenomenon was unusual in that it had occurred in a new, dry manhole.

Determining the Oxygen Level

On June 16, about midday, 6 days after the accident and 5 days after the cover had been last removed, air samples from the manhole were taken for analysis at the State laboratory of the division of industrial health, Minnesota Department of Health. Three samples were collected by lowering a rubber tube through the center hole to the depths of 5, 7½, and 9 feet below the ground surface. The cover was not removed. No combustibles were found, and no odor was present in the samples. This corroborates the testimony of two workmen, who were present at the removal of the body, that there was no odor in the manhole. The findings indicated some oxygen depletion and an increase in carbon dioxide (table 1). The oxygen level, however, after the manhole had been closed for 5 days was still high enough to sustain life, and the cause of death continued to be baffling.

On June 30, at 10 a. m., three more samples of air were taken from the manhole at the same depths (table 1). Then the cover was removed, and a mouse was rapidly lowered in a cage to the depth of 7½ feet. Within 10 seconds the mouse fell over on its side and started to kick. Ten seconds later it had stopped kicking. The cage was then pulled immediately to the surface. The mouse was found to be cyanosed and dead.

A second mouse was quickly lowered in the same way to the floor of the manhole, a depth of 9 feet. It also died in 20 seconds and was equally cyanosed. If conditions existing in the manhole on June 30 had been present on the afternoon of June 10, it would not have been necessary to look further for the cause of the workman's death, because no one could live in air containing so little oxygen—less than 3.2 percent (table 1).

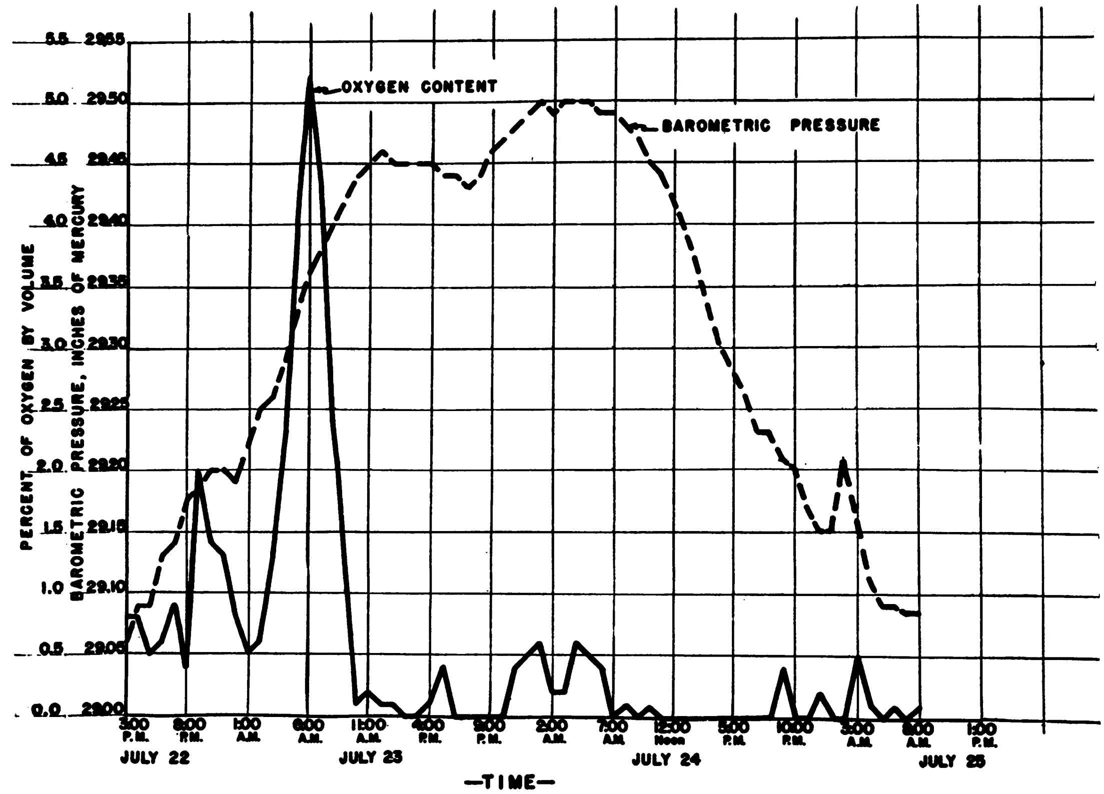
The situation was, however, still puzzling. How could conditions have changed so rapidly that a manhole entered safely in the morning could become a deathtrap by the end of the afternoon shift? Furthermore, how, when it had not been blown out with fresh air in the meantime, could a manhole, which was a deathtrap on June 10 have an oxygen level of more than 16 percent on June 16 and less than 3.2 percent on June 30?

If air contains from 19 to 21 percent oxygen, it is ordinarily considered within the range of normal. The oxygen level may drop as low as 16 percent without producing symptoms of anoxia in man. Levels ranging from 16 down to 6 percent will produce symptoms of oxygen deficiency, ranging from mild to severe, depending on the degree of exertion and other factors. Less than 6 percent is insufficient to sus-

Table 1. Analyses of oxygen and carbon dioxide content of air samples taken at collection points below ground surface

Date and content	Percentages of content by volume at collection points		
	9 feet	7½ feet	5 feet
June 16:			
Oxygen	16. 1	16. 7	17. 5
Carbon dioxide	4. 3	3. 7	3. 0
June 30:			
Oxygen	0	1. 9	3. 2
Carbon dioxide	14. 3	14. 3	12. 4

Figure 1. Studying the influence of barometric pressure—first experiment. Chart shows hourly recordings of barometric pressure and oxygen content at bottom of manhole, 9 feet below the surface, between 3 p. m., July 22, and 8 a. m., July 25, 1952.



tain life, and death from asphyxiation will occur in a few minutes.

Checking Barometric Conditions

A study of barometric pressures reported for the day of the tragedy revealed something significant: During the day of June 10 there had been a rapid fall in barometric pressure, from a reading of 29.99 at 12 noon to 29.93 at 4 p. m. Might this fact account in any way for a rapid fall in the oxygen content of the air within the manhole?

To seek an answer to this puzzling question and to find an explanation for the disappearance of oxygen, testing apparatus for determining oxygen and carbon dioxide content, air motion and air velocity, and barometer pressure was installed in a station wagon. The vehicle was stationed over the manhole and manned for 24 hours a day for 5 days, July 22 to July 26. Samples were analyzed hourly at 3 depths—5, 7½, and 9 feet from the surface. Midway in the experiment, there was a slight change in sampling depths to 3, 6, and 9 feet so that a better study could be made of the air nearer the surface. The water manhole cover was replaced with a sewer manhole cover so that the experiment could be made with more than a single opening in the cover.

Three rubber tubes were inserted to the desired depths. The edge of the cover, the space around the tubes, and the openings not in use were sealed with a mastic compound. A pipe was sealed into the center hole of the cover, and the flow of air into and out of the manhole was measured by a thermoanemometer and recorded. The direction of air flow was determined by introducing smoke in the pipe from time to time.

Hourly readings were taken for the period from 3 p. m. on July 22 to 8 a. m. on July 25. The slight change in sampling depths was made at 11 p. m. on July 23. The data recorded indicated a tendency toward an increase in oxygen content during periods of a rising barometer (fig. 1). More striking was the tendency for the oxygen content to decline during periods of a steady or falling barometer. The oxygen content fell rapidly to a point close to zero during falling barometric conditions.

The flow of air into and out of the open central pipe was extremely variable, flowing in one direction for a short time and then reversing direction. The direction of flow seemed to be influenced by wind velocity and street traffic. The air exchange through the central pipe seemed to influence only the oxygen content in the upper part of the manhole.

At no time during the study did the oxygen content in the bottom of the manhole reach the level found in the June 16 analysis. The highest level recorded was 5.2 percent. This observation led to further experiments.

Blowing With Fresh Air

For the next experiment—the station wagon with its testing apparatus was still on location, and there was no interruption between the readings made for the first test experiment and this one—the manhole was blown out with fresh air on the morning of July 25, and immediate tests showed oxygen levels ranging from 18.8 percent at the bottom of the manhole to 19.3 percent at the 3-foot level. The manhole sewer cover was again in place and sealed as in the preceding experiment. Hourly tests were run during the 30-hour period from 9 a. m. July 25 to 2 p. m. on July 26 (fig. 2), and readings were taken at depths of 3, 6, and 9 feet.

The oxygen content dropped rapidly, particularly at the greater depths, from 18.8 at the beginning of this experiment to 1.4 percent at 3 o'clock on the first afternoon. Thus, in a few hours, the oxygen level dropped from the so-called normal range of 19 to 21 percent to a point insufficient to support life. Here at last it had been demonstrated that in the deathtrap very rapid changes were, on occasion, taking place. If these changes duplicated those which might have occurred on June 10, perhaps herein lay an explanation for the death from suffocation of the plumbing company employee. At the termination of this second experiment, the oxygen level was almost zero: 0.9, 0.1, and 0.3 percent at the depths of 3, 6, and 9 feet. The corresponding carbon dioxide levels were 14.8, 15.2, and 14.5 percent.

However, it was noted that while the oxygen content in the manhole on July 25 was falling rapidly, the barometric pressure was slowly rising, a condition which did not exist on June 10. Perhaps there might be some factor other than barometric pressure which might influence the oxygen and carbon dioxide changes.

Examining Soil Samples

In a further search for the unknown factor causing oxygen depletion in the deathtrap, the manhole was revisited on September 22, 1952, to obtain soil samples.

The manhole was blown out with fresh air before it was entered. Soil, bits of dried mortar, debris, and extraneous material commonly found in filled areas were found in the first 6 inches of surface at the bottom. Beneath this layer there was a very solid material which had the uniform appearance of a sand rock impregnated with oil. The hard material was black and had an odor resembling the oil ordinarily applied to roads. The total depth of the oil-sand-rock and its extent were not determined.

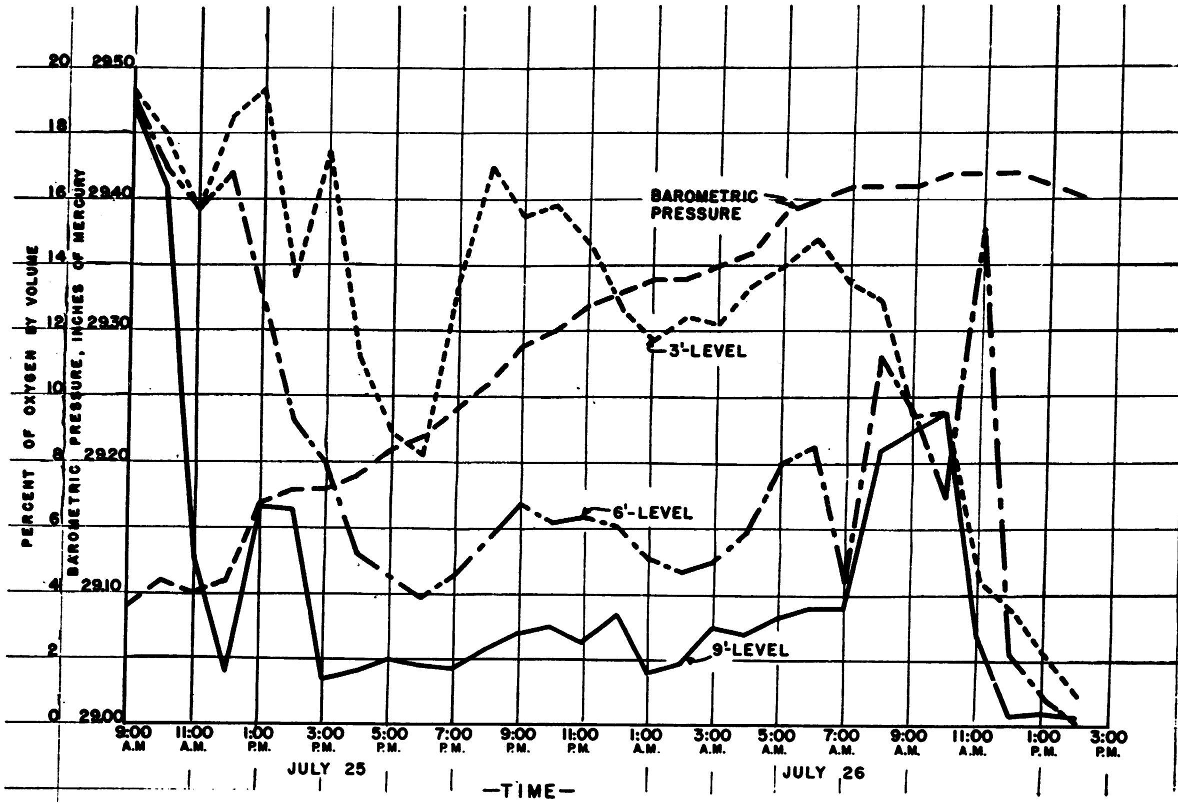
Samples of the oil-sand-rock and of the overlying soil debris were taken to the laboratory. There, samples of clean sand taken from an excavation and of black dirt from a garden were compared with the samples of the oil-sand-rock, and all three were tested for chemical oxygen demand. The results of these tests are shown below:

Samples	*Grams of oxygen per gram of soil*
Oil-sand-rock from test manhole	0.33
Black garden dirt	.12
Clean sand from excavation	0

There was almost no oxygen absorption by the clean sand. The black garden dirt absorbed some oxygen. The hard oil-sand-rock obtained from the manhole had, however, a much higher oxygen demand and produced carbon dioxide. The oil-sand-rock used oxygen at a rate three times as fast as garden dirt and infinitely faster than the clean sand.

The oil-sand-rock was extracted with benzol.

Figure 2. Results of the second experiment—air analysis of deathtrap manhole after it was blown out with fresh air on the morning of July 25, 1952. Barometric pressure and oxygen content at 3-, 6-, and 9-foot levels are shown for every hour from 9 a. m., July 25, through 2 p. m., July 26, 1952.



The residue left after extraction appeared to be sand. When the benzol was evaporated from the extract, a black tarry residue was left. The tarry material appeared to be the substance responsible for the consumption of oxygen and production of carbon dioxide.

The absorption of oxygen and production of carbon dioxide in the manhole were more rapid than would be expected from the rate of oxygen absorption by the hard oil-sand-rock as the process was observed in the laboratory. However, nothing is known about the extent of the oil-sand layer in the vicinity of the manhole. There may be an extensive oxygen-depleted area around the manhole where the oxygen has been replaced by carbon dioxide. If such is true, diffusion of the relatively small amount of air in the manhole into the surrounding subsoil would account for the rapid changes taking place in the manhole. Furthermore, the manhole is located in a relatively low topographic area where there may also be some organic matter in the surrounding subsoil, which might also contribute to the oxygen depletion.

A further examination of the data recorded in the first two studies (figs. 1 and 2) led to the conclusion that, although there is some correlation between oxygen depletion in the manhole and changes in barometric pressure, in this case the important factor appeared to be that there were chemical changes brought about by the oil-sand-rock and by the organic substances in the surrounding subsoil. The effect of changes in barometric pressure was probably through its influence of the pressure rise and fall on the rate of diffusion of air and gases through the walls of the manhole.

Like Sites, Like Findings

The question then presented itself—was this manhole unique or were abnormal oxygen con-

Table 2. Air analysis of 19 manholes in low or swampy areas

Manhole	Carbon dioxide (percent)	Oxygen (percent)
1	0.7	18.5
2	.7	18.0
3	.9	19.1
4	7.2	11.5
5	2.7	16.0
6	5.1	14.3
7	2.8	17.0
8	2.6	17.2
9	8.3	0
10	1.5	19.7
11	7.4	11.0
12	4.5	14.9
13	1.2	19.2
14	.2	20.5
15	3.9	17.0
16	15.1	3.5
17	2.4	18.8
18	6.6	14.4
19	5.0	15.9

centrations a common finding in closed manholes? In order to arrive at some conclusion, a further investigation was undertaken of 44 water main manholes in Minneapolis. They were of similar size and construction. They were dissimilar only in topographic location and in the nature of the surrounding subsoil. Nineteen were in low or swampy areas where the subsoil might be expected to contain a large amount of organic matter. Twenty-five were on relatively high ground and, so far as could be ascertained, in sandy subsoil which might be expected to contain little organic matter.

The same method used in testing the deathtrap manhole was also followed in this experiment. The percentage of oxygen concentration by volume in the group of 19 (see table 2) varied from 0 to 20.5 with an average concentration of 15.1. Two of these manholes contained less than 6 percent oxygen and were, therefore, deathtraps. Four others contained less than 16 percent oxygen, which would be sufficiently low to produce symptoms of anoxia in anyone entering them. Only 4 of the 19 had oxygen levels within the normal range. There was no percentage of oxygen lower than 17.3 in the group of 25 located on higher ground.

These findings led to the general conclusion that the oxygen content of manholes in low and swampy areas can be expected to be considerably below that in the general atmosphere and may drop to dangerously low levels.

Studying a Control Manhole

To clarify further the effect of barometric pressure changes and the rapidity of diffusion through the walls of the typical concrete brick manhole, a study which would eliminate the factor of oxygen absorption by the soil was undertaken.

A manhole, 7 feet deep, on high ground in clean sandy subsoil was selected for this control experiment. The street pavement in the area was similar to that where the death occurred: a brick surface set on a concrete base. Portions of the paved area had been patched with bituminous material. The testing apparatus and the method of collecting air samples were similar to those used in the first two studies.

Hourly readings of barometric pressure were taken over a 27-hour period, beginning at 12 noon on November 3, 1952, and ending at 2 p. m. on November 4. Oxygen and carbon dioxide determinations were made for samples obtained at depths of 3½ and 7 feet. The oxygen levels at 12 noon were 19.4 and 19 percent.

During the first 11 hours of this study, the barometer fell rapidly from 29.53 to 29.05 at 11 p. m. The fall in pressure was reflected in a gradual decline in the oxygen content (from 19 to 18 percent for the same 11 hours). Then the barometric pressure leveled off, and the oxygen content rose to as high as 20.7 percent. This change in oxygen content was thought to represent only the effect of barometric pressure changes. The return of the oxygen content to the normal range was interpreted to mean that in the soil surrounding the control manhole no organic matter or extraneous materials were present to account for the absorption of oxygen. As further proof of this interpretation, a sample of the sand taken from the bottom of the manhole was analyzed. The chemical oxygen demand was found to be extremely low: 0.008 gram of oxygen per gram of soil.

Table 3. Air analysis in control manhole after filling with nitrogen (samples taken 3½ and 7 feet from surface)

Date and time, 1952	Percentage of oxygen by volume at—		Percentage of carbon dioxide by volume at—		Barometric pressure (inches of mercury)
	7 ft.	3½ ft.	7 ft.	3½ ft.	
Nov. 4:					
4 p. m.	0.2	0	0	0	28.88
5 p. m.	.6	1.0	0	0	28.86
6 p. m.	1.0	1.1	.2	.1	28.84
7 p. m.	1.1	1.2	.1	.4	28.82
8 p. m.	1.4	2.1	.2	.5	28.80
9 p. m.	3.0	3.5	.5	.5	28.77
10 p. m.	3.5	4.3	.4	.5	28.75
11 p. m.	4.6	4.7	.2	.2	28.74
12 p. m.	5.4	5.6	.2	.6	28.74
Nov. 5:					
1 a. m.	6.4	6.5	.3	.4	28.73
2 a. m.	6.9	7.5	.4	.3	28.74
3 a. m.	7.6	7.9	.3	.5	28.74
4 a. m.	8.6	9.4	.7	.6	28.76
5 a. m.	10.6	10.2	.4	.9	28.78
6 a. m.	11.2	11.6	.7	.2	28.80
7 a. m.	11.8	13.0	.3	.7	28.82
8 a. m.	12.8	13.7	.2	.4	28.83
9 a. m.	14.0	14.4	.2	.3	28.85
10 a. m.	14.6	14.7	.3	.3	28.86
11 a. m.	15.5	15.5	.2	0	28.85
12 noon	15.1	16.1	.2	.2	28.85
1 p. m.	16.7	16.6	.3	.2	28.85
2 p. m.	17.0	16.6	.2	.3	28.86
3 p. m.	16.5	16.8	0	.3	28.89
4 p. m.	16.9	17.1	.1	.3	28.91
5 p. m.	17.3	17.8	0	.2	28.94
6 p. m.	17.9	18.2	0	.2	28.97
7 p. m.	17.5	18.0	.1	.1	28.98
8 p. m.	18.0	18.2	0	.8	28.98
9 p. m.	18.3	18.4	0	0	29.00
10 p. m.	18.3	18.3	0	0	29.02
11 p. m.	18.4	18.2	.2	0	29.04
12 p. m.	18.2	18.8	0	0	29.07
Nov. 6:					
1 a. m.	19.0	19.0	0	.2	29.08
2 a. m.	19.0	19.0	0	0	29.10
3 a. m.	18.8	19.2	0	0	29.12
4 a. m.	19.0	19.0	0	0	29.14
5 a. m.	19.0	19.0	0	0	29.18
6 a. m.	19.0	18.9	0	0	29.20
7 a. m.	19.3	19.6	0	0	29.00

Displacing Air With Nitrogen

To determine in some measure the rapidity with which oxygen would be restored to normal by natural means, the oxygen in the control manhole was reduced to zero by displacing the air in the manhole with nitrogen. Immediately after the introduction of the nitrogen, all holes in and around the cover were sealed. Air samples were taken through rubber tubes, as in the earlier experiments, and at depths of 3½ and 7 feet. The oxygen content rose rapidly and steadily from zero to 19.6 percent in 24 hours. During the period of study, which began at 4 p. m. on November 4, 1952, and ended at 7 a. m. on November 6, the barometric pressure dropped steadily from 28.88 to 28.73 at 1 p. m. on November 5, and thereafter rose steadily to a high of 29.20 at 6 p. m. on November 6 (see table 3). There were no measurements made of air velocities in and out of this manhole because it was completely sealed, thereby preventing entry of atmospheric oxygen.

This final experiment demonstrated the rapid diffusion of gases through the walls and floor of a manhole into the surrounding soil and from the surrounding soil into the manhole. It further indicated that where a manhole is constructed in soil which has a low oxygen demand, the natural process of diffusion may be expected to maintain the oxygen content of the manhole at near the acceptable range of 19 to 21 percent.

Summary and Conclusions

This series of experiments emphasized the dangerous conditions that might be found in manholes with respect to oxygen depletion and the necessity for caution and adequate ventilation before entering or working in such places. No manhole should be considered safe until it has in some way been demonstrated to contain sufficient oxygen or has by some mechanical means been freshly blown cut with fresh air.

It may be generally concluded that changes in barometric pressure are relatively minor factors in altering the oxygen content of air in manholes and that the presence of organic matter and other extraneous materials which have a chemical oxygen demand is a factor of major importance.

Four specific conclusions, however, were reached: Manholes, particularly those in low or swampy areas, are potentially dangerous in respect to oxygen depletion. There may be substances in the subsoil other than vegetable matter which may increase the chemical oxygen demand. There is free and rapid diffusion of gases through the walls and floor of manholes. The flow of air through the manhole cover openings is ineffective under all conditions in maintaining the air within the manhole in equilibrium with the outside air.

Further study of this subject might be indicated since this investigation in Minneapolis was not exhaustive. The effect of such factors as change in seasons, frost, rainfall, traffic load, and variations in type of street surfaces might bear investigation.

REFERENCE

(*1*) Raschka, G. J., and Uber, W. J.: Oxygen depletion in a sewer manhole. Sewage and Indust. Wastes 23: 802-807 (1951).

Dermatitis in the Poultry-Dressing Industry

Although available statistical data are meager, investigators in the occupational health field are of the opinion that dermatitis is a factor in the poultry-dressing industry by virtue of hazards present in that trade. Some of these hazards are:

(1) Trauma—Such as cuts and abrasions which can occur from the use of knives or from the claws and the hardened feather quills.

(2) Bacterial Infections—Such as erysipeloid, tularemia and brucellosis.

(3) Fungous Infections—These may be rarely transmitted from the fowl itself. Monilial infection can occur as a result of constant moist environment to which the men are exposed.

(4) Parasitic Infestations—The chicken mites and chicken lice are well known to attack human beings and cause definite cases of dermatitis.

The precautionary measures recommended in such cases are as follows:

(1) Those individuals working in wet environments should be provided with boots or rubbers and rubber aprons in order to avoid standing or coming in contact with wet floors, trays, and counters during the course of the work day.

(2) Those who are handling the live fowls should wear coveralls which are designed to protect the extremities, both upper and lower, and which, when worn properly, fasten around the neck. These individuals should also wear washable cotton or other fabric gloves which can be laundered at least once a week.

(3) Individuals exposed to the entrails should, if possible, wear rubber gloves; if gloves are not feasible, they should at least be provided with strategically placed washing facilities which can be used with relative frequency.

(4) All cuts and abrasions should be promptly washed and sterilized with 70 percent alcohol or one of the other types of local antiseptics.