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CAUSES OF SOME ACCIDENTS FROM GAS APPLIANCES

An investigation conducted in Baltimore in cooperation with the Baltimore Health Department, United States Public Health Service, and The Consolidated Gas Electric Light & Power Co., of Baltimore, Md.

BY

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AN INVESTIGATION CONDUCTED IN BALTIMORE IN COOPERATION WITH THE BALTIMORE HEALTH DEPARTMENT, UNITED STATES PUBLIC HEALTH SERVICE, AND THE CONSOLIDATED GAS ELECTRIC LIGHT & POWER CO., OF BALTIMORE, MD

By I. Vernon Brumbaugh

ABSTRACT

Several fatal asphyxiations from carbon monoxide during the beginning of the winter of 1922–23 prompted the mayor of Baltimore to order an investigation by the health department. Because the Bureau of Standards had studied gas utilization problems it was requested to cooperate.

During the investigation studies were made of causes of asphyxiation in 18 cases which involved the temporary disablement of 48 persons and the death of 5. Three of the deaths occurred where persons were sleeping in closed bedrooms while improper room heaters were in use. Tests of the heaters revealed that carbon monoxide was produced in large quantities, even when operated in a normal atmosphere (20.9 per cent oxygen). One death resulted from a cooking appliance being pulled loose from an old rubber tube connection by an intoxicated person. Another death occurred where the connection of a flexible tube was accidentally or intentionally pulled loose from a room heater. Of the 48 persons partially asphyxiated 13 were unconscious when found and were revived by prompt treatment. Deaths believed to be suicide were not investigated.

Among the appliances that were found to produce carbon monoxide were 8 water heaters, 6 room heaters, and 5 cooking stoves. The causes were attributed to faults in design, improper installation or adjustment, deterioration or clogging of vital parts, carelessness or ignorance, etc.

In connection with the investigation, 11 tests of the performance of appliances were made in an unventilated chamber. The extent to which the oxygen content of the atmosphere can be depleted without causing the formation of carbon monoxide depends on the manner of aeration of the flame. In atmospheres depleted to about 16 per cent of oxygen the gas was completely burned if the flame was well aerated. The possibility of poisoning from appliances with well-aerated flames is, therefore, exceedingly remote.

A few tests of appliances were made with various pressures of gas. Most appliances can be and should be properly adjusted to meet the prevailing operating pressures. Most appliances of faulty design can be readily remodeled to improve their safety and adaptability.

It it were possible to connect room heaters and all appliances burning large quantities of gas or used in poorly ventilated rooms to properly constructed flues having positive drafts, and to prevent the sale and installation of appliances which do not have a satisfactory range of safe operation, accidental asphyxiations from carbon monoxide would be relatively few. Many accidents could be avoided if appliances were inspected by competent persons to determine whether they are properly installed, properly adjusted, and in proper condition for operation.

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I. INTRODUCTION

The use of gas for domestic and industrial heating purposes has rapidly increased from year to year. This can be largely attributed to the numerous applications in which heating with gas can be done more conveniently, cleanly, and under better control and often with greater economy than with solid fuels. Heating water for domestic use with gas, for example, is steadily increasing. Also, the convenience and attractiveness of space heaters, with no ashes and odors, have caused a tremendous increase of their use for heating homes and office buildings. The uncertainty of supply of other fuels has added to the relatively recent popularity of gas heating. It has proved to be very economical to equip homes and office buildings with space heaters for use during the mild weather of the fall and spring months. They are also used in many instances as auxiliary heaters, even during the winter months.

A large number of appliances of all types have been required to meet this general demand. This has resulted in an increase of the number of manufacturers, many of whom are not familiar with combustion problems or have not acquired a knowledge of the proper design of appliances. There is very little published literature concerning the principles of design of appliances, which further hampers the progress of the art and is the greatest impediment to those who do not possess development facilities.

The laws of combustion are quite simple. When a fuel is completely burned, carbon dioxide and water are formed. If the combustion is incomplete, carbon monoxide, a poisonous gas, is produced.

To completely burn a given volume of any fuel requires that enough oxygen must be supplied from the air to the region of the flame before the combustible material is cooled below the minimum temperature at which combustion takes place. Carbon monoxide can be liberated, therefore, with the products of combustion from wood, coal, coke, all gaseous fuels, kerosene, crude oil, etc.

Throughout the United States there has been a noticeable increase of the number of accidents attributed to carbon monoxide asphyxiation. During the early winter of 1922–23 there were a number of persons either partially or fatally asphyxiated in Baltimore, Md., by carbon monoxide produced by domestic gas appliances. Accounts of asphyxiations were published almost daily by the press. Two incidents in particular attracted much attention. In one instance a person was fatally asphyxiated by improper combustion caused by placing a cap over the vent of a water heater, the object being to "trap the heat." The other case was discovered on Christmas Day when two persons were found dead in bed in a closed bedroom that was being heated by a gas room heater. The coroner believed the room heater was being operated properly and was in good condition. The opinion was expressed that the deaths were caused by the quality of the gas. A few days after this latter case, prompted largely by reports in the press of more instances of poisoning, the mayor of Baltimore ordered the city health department, of which Dr. C. Hampson Jones was commissioner, to undertake an investigation of the causes of what appeared to be an unprecedented number of asphyxiations. Dr. J. H. Shrader, director of the bureau of chemistry and food of the city health department, was appointed to direct the investigation.

The United States Public Health Service and the Bureau of Mines had made studies of the effect of carbon monoxide poisoning on the human body, and the Bureau of Standards for several years had been investigating the design of gas burners, and had made some studies of proper and improper operation of different types of gas appliances. Consequently, the United States Public Health Service, the Bureau of Mines, and the Bureau of Standards were invited and agreed to enter jointly into the investigation.

Plans for the investigation were formed in conferences by Dr. J. H. Shrader; Dr. R. R. Sayers, surgeon, United States Public Health Service, and chief surgeon, Bureau of Mines; Dr. C. W. Mitchell, passed assistant surgeon, United States Public Health Service, who was assigned to the medical work; W. M. Berry, gas engineer, in charge of the gas engineering section of the Bureau of Standards; and I. V. Brumbaugh, who was assigned to the technical problems by the Bureau of Standards.

It was decided that the investigation should be approached from three angles. The assignment of a major responsibility to each interested party was as follows: (1) The health department of Baltimore assumed the responsibility of investigating any chemical problems pertaining to the constituents in the gas before or after combustion. (2) The Public Health Service studied all problems of a medical nature, such as treatment for carbon monoxide poisoning and the after effects of gas poisoning. (3) The Bureau of Standards undertook to determine the sources of carbon monoxide in the various cases as soon as possible after they occurred. This necessitated considerable study at the scene of accidents.

Throughout the investigation the Consolidated Gas Electric Light & Power Co. cooperated in every possible manner and freely supplied personnel, information, testing facilities, and equipment. Most of the gas analyses reported in this paper were made by an employee of the gas company.

It was apparent that in order to obtain some of the desired information the use of an unventilated chamber was necessary. A room in the building of the health department of Baltimore was hastily prepared and equipped for this purpose (fig. 1). In this chamber appliances of different types could be operated until the flame was smothered through deficiency of oxygen.

A general report of the investigation was rendered to the mayor of Baltimore and a résumé of the investigation has been published in the American Journal of Public Health.[1] A medical study of the persons poisoned by carbon monoxide is the subject of a report prepared by Dr. C. W. Mitchell, which is in the files of the United States Public Health Service.

This publication contains an account of the conditions, design, and manner of operation of appliances, and the probable rate of formation of carbon monoxide in connection with accidents occurring during the months of February, March, and April, 1923. Reported herein are studies of the effect of diminished oxygen content of the atmosphere upon the performance of appliances during operation in the unventilated chamber. A few tests were made of the effect of excessive rates of consumption produced by variations in gas pressure. The general information developed from the investigation has suggested the inclusion of a summation of the causes of improper combustion by some types of appliances and points to some features which are necessary for the safety and adaptability of appliances.

It is hoped that the information contained in this report will be useful to further an improvement in the design of those types of appliances which are causing improper combustion when operated

[1] J. H. Shrader and C. W. Mitchell, "Investigation of the hazards from the use of manufactured gas in Baltimore." Am. Jour. of Pub. Health; April, 1924.

under reasonable gas service conditions. If this publication in any measure assists in improving and extending the proper utilization of gas, its intent will be fulfilled.

1. CONDITIONS OF GAS SERVICE IN BALTIMORE, MD.

The Baltimore Consolidated Gas Electric Light & Power Co. has a contract with the Bethlehem Steel Co., Sparrows Point, Md., whereby coke-oven gas not needed by the steel company is purchased and pumped to a holder at the Spring Gardens station of the gas company. The quantity of gas received from Sparrows Point varies largely with the number of coke ovens in operation, the coking time, and the amount of gas required by the different mills of the steel company. The coke-oven gas, before entering the distributing mains of Baltimore, is purified and mixed with carburetted water gas manufactured by the gas company. The proportion in which the two gases are mixed may vary from day to day and especially with the season of the year, and depends on the quantity received from Sparrows Point and the amount used by the public.

There has been a marked and gradual increase in the volume of gas consumed in Baltimore from year to year. The total sales were 3,239,755,700 cubic feet in 1916 and 10,015,893,500 cubic feet in 1923. During the three months of the investigation 3,045,400,000 cubic feet were consumed, as compared with 2,547,400,000 cubic feet during the corresponding months of the previous year, an increase of 19.5 per cent.

The Public Service Commission of Maryland has established a standard of heating value which is to be supplied in Baltimore and is as follows: The average monthly heating value must not be less than 500 B. t. u.[2] per cubic foot; the maximum daily average of the heating value must not exceed 520 B. t. u. per cubic foot; and the minimum daily average of heating value must not be less than 490 B. t. u. per cubic foot.

The volume of gas that flows from an orifice of a given size at a given pressure depends on the specific gravity of the gas; a light gas flows with greater velocity than a heavy gas. Because coke-oven gas is lighter in weight than carburetted water gas the specific gravity of a mixture will depend on the proportions of these two gases. Coke-oven gas, which has a heating value of about 500 B. t. u. per cubic foot, will average about 0.44 specific gravity. Carburetted water gas has a specific gravity of about 0.65 when the heating value is 500 B. t. u. per cubic foot.

For a given pressure the rate of flow of gas varies inversely as the square root of the specific gravity. If it is assumed that a burner is

[2] One B. t. u. (British thermal unit) is the quantity of heat necessary to raise the temperature of 1 pound of water 1° F.

being supplied with 20 cubic feet per hour of gas of 0.61 specific gravity, and the specific gravity is changed to 0.43, the rate of flow of gas will be

$$20\sqrt{\frac{0.61}{0.43}}=23.8 \text{ cubic feet per hour}$$

an increase of only 3.8 cubic feet per hour.

The effect of change of specific gravity of gas on the operation of a burner is discussed and illustrated in Bureau of Standards Technologic Paper No. 222.[3]

During the period of the investigation (February to April, 1923) the actual variation of daily average heating values was from 490 to 518 B. t. u. and the specific gravities from 0.43 to 0.61. As shown by the records of the Public Service Commission of Maryland, the conditions of service had not changed appreciably for several years.

The variations in the heating value and specific gravity during the period of the investigation have been considered in relation to their influence on combustion, but no evidence was obtained which would lead one to believe that they were appreciable causes of improper combustion.

The Public Service Commission of Maryland has established the following requirements for pressure of the gas to be maintained in Baltimore: The minimum pressure at the service outlet to the consumer must not be below 2 inches and the maximum pressure must not be above 6 inches. The daily variation at any one point must not be greater than 100 per cent of the minimum pressure.

The pressure records of the commission taken from the various districts of the city were examined. The records show that there are a few consumers in the vicinity of the gas plant at Spring Gardens where the pressure sometimes exceeds the maximum. Pressures as high as 8 inches have been recorded, but only during the periods of peak demand. No cases of carbon monoxide poisoning were encountered in this district.

2. COMBUSTION OF GAS

Fuels may contain combustible products either as pure carbon (C), hydrogen (H_2), or combinations of carbon and hydrogen in the form of methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), etc. In the process of making manufactured gases, such as water gas, oil gas, and coal and coke-oven gas, carbon monoxide (CO), a combustible gas, is formed.

[3] B. S. Tech. Paper No. 222, Relative Usefulness of Gases of Different Heating Value and Adjustments of Burners for Changes in Heating Value and Specific Gravity, by Walter M. Berry, I. V. Brumbaugh, J. H. Eiseman, G. F. Moulton, and G. B. Shawn.

If the combustion is complete, in the reactions that cause the liberation of heat, hydrogen combines with oxygen to form water, and carbon, whether in the elementary form or combined as a hydrocarbon or as carbon monoxide, combines with oxygen to form carbon dioxide. Thus when gases containing combinations of carbon and hydrogen are completely burned both carbon dioxide and water are formed.

If, however, any fuel containing carbon is burned in the absence of a sufficient quantity of oxygen, or if for any other reason combustion is not complete, some carbon monoxide is always formed. This gas is odorless, but it is frequently accompanied by other substances which have an odor and which betray the fact that combustion is not complete. These odorous substances are not always formed and their absence can not be relied upon as an indication that combustion is complete.

3. INJURIOUS ACTION OF CARBON MONOXIDE ON THE HUMAN BODY

It is well known to everyone that oxygen is absorbed from the air we breathe into the lungs and is distributed by the blood stream to every part of the body. A brief interruption of the oxygen supply is fatal. Hæmoglobin (the red coloring matter of the blood) is the active oxygen carrier. It combines much more readily with carbon monoxide than with oxygen, and the portion so combined does not serve to carry oxygen at all; hence a small percentage of carbon monoxide in the atmosphere will interfere with the supply of oxygen normally required by the tissues of the body.

When a person breathes air containing carbon monoxide, this gas is gradually absorbed by the hæmoglobin until an equilibrium between carbon monoxide, oxygen, and hæmoglobin is reached (unless death ensues and interrupts breathing). The extent to which a person is affected will depend on the duration of the exposure, the concentration of carbon monoxide in the atmosphere, and whether the subject is active or at rest.

Tests made by The United States Public Health Service [4] show that if a person at rest is exposed to an atmosphere with 4 parts of carbon monoxide in 10,000 (0.04 per cent), the hæmoglobin will become 15 to 19 per cent saturated with carbon monoxide in one hour, and 21 to 28 per cent saturated at the end of two hours. If the person is exercising strenuously, the same concentration (0.04 per cent) of carbon monoxide will cause 23 per cent of the hæmoglobin to become saturated in one hour. A concentration of carbon mon-

[4] R. R. Sayers, F. V. Meriwether, and W. P. Yant, Physiological Effects of Exposure to Low Concentrations of Carbon Monoxide; pp. 15–16.

oxide in the atmosphere as low as this can cause headache, dizziness, nausea and vomiting, etc., if the exposure is of sufficient duration. When 75 to 80 per cent of the hæmoglobin is in combination with carbon monoxide the remaining hæmoglobin is insufficient to supply oxygen at the rate which is necessary to support life. Carbon monoxide has neither odor nor taste and is not an irritant either externally or internally. The body is poisoned and health is impaired because the various organs can not function properly when the cells and tissues are deprived of the oxygen they require.

E. R. Hayhurst [5] says: "As a rough estimate it may be stated that a man who has breathed air containing 0.2 per cent of carbon monoxide for four or five hours or 0.4 per cent for one hour will die. In air containing 2 to 5 per cent of carbon monoxide, as after an explosion of coal dust, nearly all of the hæmoglobin is combined by the first few breaths drawn, and death follows almost as quickly as in drowning."

Since carbon monoxide is gradually absorbed by the blood a person can be subjected to a dangerous concentration for a short period of time without apparent ill effects. It must be remembered, however, that the elimination of carbon monoxide from the blood when pure air is breathed is also gradual. Therefore, a person should exercise great care when being exposed at intervals to dangerous concentrations.

(a) CHRONIC CARBON MONOXIDE POISONING

It appears from the literature that some people, usually those with strong bodies, may frequently breathe air containing a small but toxic percentage of carbon monoxide, and may be more tolerant to poisoning than others who suffer from time to time with various ailments.

Watkins [6] states that symptons of chronic carbon monoxide poisoning are: Persistent and distressing headache, nausea and vomiting, attacks of giddiness, muscular weakness, lack of coordination, rapid fatigue, heart trouble, anemia, nervous disorders, neuritis with ensuing paralysis, melancholia or hallucinations, impaired mental alertness, etc. It is apparent that a person's health may be greatly impaired from continuous or frequent exposure to toxic quantities of carbon monoxide.

The Bureau of Standards from time to time has responded to requests from residents of Washington for advice concerning their gas appliances. A number of cases of apparent chronic carbon

[5] Kober and Hayhurst, Industrial Health, p. 381; 1924.

[6] J. A. Watkins, Carbon Monoxide Poisoning in the Steel Industry, Bureau of Mines Tech. Paper No. 156.

monoxide poisoning have been discovered, and letters received from several sufferers indicate that in each case an immediate improvement of health resulted when the source of carbon monoxide was removed. One of the cases in which the symptoms were similar to those of neuritis appears to have resulted from the use of a solid top on a stove designed for a grate top. In another case, antiquated two-piece burners which allowed gas to escape unburned from the junctions between the halves seems to have been the source of frequent and severe headaches which were unsuccessfully treated by a physician who apparently did not suspect their real cause. It should be stated that the gas industry has for years discouraged the manufacture and use of burners of this type. In one of the most severe cases encountered in Washington, headache, nausea, weakness and fatigue all occurred apparently as the result of using a range equipped with "flame spreaders" of a type which prevented the circulation of enough air to the flame. In this case the burners were also located too near the grate.

(b) ACUTE CARBON MONOXIDE POISONING

The unusual number of cases of acute carbon monoxide poisoning caused the mayor to order this investigation. Acute cases of poisoning are considered to be those in which carbon monoxide is breathed in sufficient quantity to produce symptoms in a short time. During the investigation, however, several cases of chronic poisoning were encountered and tests of the appliances that were used are reported in this paper.

When people are poisoned, either slightly or severely, they should be taken at once to an atmosphere of pure air and a physician summoned. Many of the larger gas companies maintain an emergency service for cases of this kind and should be notified at once when one occurs. The Baltimore Gas Co. has a complete resuscitation outfit that is available at all hours. If the patient is completely overcome, artificial respiration should be applied for at least two hours unless normal breathing has been resumed. Anyone desiring more specific information regarding first aid should read the 1923 report of the accident prevention committee of the American Gas Association, which contains the most recent recommendations concerning the resuscitation and treatment of persons asphyxiated by carbon monoxide. This subject of carbon monoxide is comprehensively treated in United States Public Health Bulletin No. 150.[7] The publication also contains an extensive bibliography.

[7] Carbon-Monoxide Literature, by R. R. Sayers and Sara J. Davenport.

II. SPECIAL TESTING METHODS EMPLOYED

1. IODINE-PENTOXIDE APPARATUS

The iodine-pentoxide method was used to determine the amount of carbon monoxide in the samples analyzed. The apparatus used was one maintained by the Consolidated Gas Electric Light & Power Co. for the testing of various gas appliances. The principle of the iodine-pentoxide method is based on the reaction of carbon monoxide with iodine pentoxide when the temperature is about 155° C. (311° F.). The amount of iodine liberated by a sample containing carbon monoxide is in direct proportion to the amount of carbon monoxide present. The reaction is as follows:

$$I_2O_5 + 5CO = I_2 + 5CO_2$$

(iodine-pentoxide) + (carbon monoxide) (iodine) + (carbon dioxide)

By means of this apparatus the percentage of carbon monoxide in the products of combustion from an appliance can be determined accurately to one-thousandth of a per cent.

A description of the various units of the iodine-pentoxide apparatus and their function is given in Bureau of Standards Technologic Paper No. 222.[8]

2. UNVENTILATED CHAMBER USED IN TESTS

In order to determine the amount of carbon monoxide produced by some appliances and to study their performance when the oxygen content of a room is greatly diminished (which simulates the effect of extremely poor ventilation) the health department of Baltimore constructed a test chamber in which ventilation could be made negligible. The volume of the chamber proper was 1,120 cubic feet. A sketch which shows the manner of construction of the chamber and the arrangement of apparatus used for testing is shown in Figure 1.

The doors of the vestibule to the chamber were made of the refrigerator type with rubber seals, and could be firmly closed by clamps. The walls and ceiling were coated with a glue sizing, papered, and then varnished. Tightly fitted linoleum was cemented to the floor and then varnished.

In order to thoroughly ventilate the chamber before conducting a test an exhaust fan was installed in a vent pipe leading from the ceiling. During the progress of a test the vent was closed by a water seal. To insure equal distribution of the products of combustion and thus secure an average sample of the atmosphere an agitator fan was installed on a shelf in a corner. The gas meter, pressure gauge, and pressure regulator were connected into the gas supply

[8] See footnote 3, p. 53.

line outside of the chamber. To sample the chamber atmosphere a 2-liter aspirator bottle filled with water and placed outside of the chamber was connected to a tube that terminated in the center of the chamber and 5 feet from the floor. Immediately before drawing a sample an aspirator was used to purge the tube. It required about one minute for the water to flow from the sample bottle.

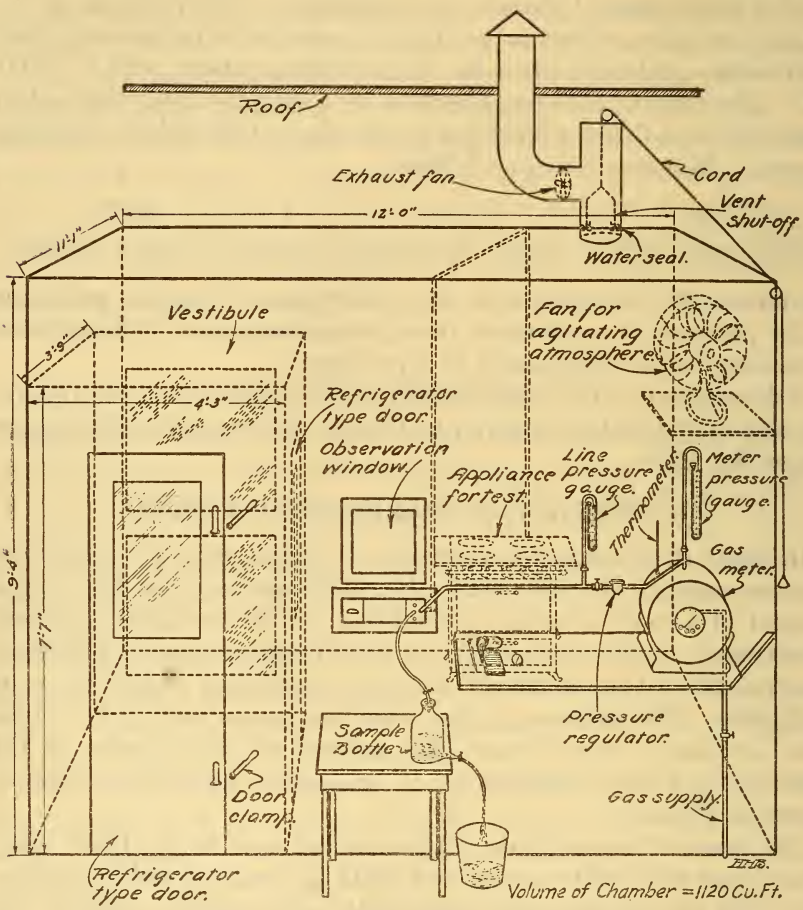

FIG. 1.—*Diagram of unventilated chamber*

3. METHOD OF COMPUTING THE RATE OF FORMATION OF CARBON MONOXIDE

The rate at which carbon monoxide was formed by an appliance was computed from analyses of samples taken in either of two ways. The gases containing products of combustion were sampled as they issued from the appliance or the appliance was operated in the unventilated chamber and an analysis of the atmosphere was made.

The former method is preferred and was used in this investigation as much as possible. A much greater number of samples can be procured in a relatively short length of time.

The following example shows the procedure used in computing the rate of formation of carbon monoxide when the sample was taken where the burned gases issue from the appliance. Let it be assumed that a sample of gases containing products of combustion contained:

	Per cent
CO_2	3. 0
O_2	14. 9
CO	. 631
N_2 (by difference)	81. 4

The oxygen content shows the sample contained a large amount of excess air. Since normal air consists of 20.9 per cent of oxygen by volume, the above sample was only

$$\frac{(20.9-14.9)\times 100}{20.9}=28.7 \text{ per cent products of combustion.}$$

Therefore on the air-free basis the sample contained:

	Per cent
CO_2	$=2.0 \div 0.287=10.4$
CO	$=0.631 \div 0.287=2.20$
N_2 (by difference)	$=87.4$

The quantity of carbon dioxide that is produced when a given volume of gas is completely burned is readily computed from an analysis of the constituents. The combustion of a cubic foot of the gas used at the time the above sample was obtained produces 0.484 cubic foot of carbon dioxide. Since a given volume of carbon monoxide burns to the same volume of carbon dioxide the above sample, if completely burned, would have contained approximately $10.4+2.2=12.6$ per cent of carbon dioxide on the air-free basis. Therefore the appliance in this case was producing $\frac{2.20}{12.60}\times 0.484=0.0845$ cubic foot of carbon monoxide during the combustion of a cubic foot of gas. The appliance was consuming gas at the rate of 15.7 cubic feet per hour. Carbon monoxide was being produced at the rate of $0.0845\times 15.7=1.33$ cubic feet per hour.

When an appliance was operated in the unventilated chamber, the quantity of carbon monoxide that was produced was computed by multiplying the percentage in the sample by the volume of the chamber (1,120 cubic feet).

III. CASES OF ASPHYXIATION FROM CARBON MONOXIDE

While the investigation was being conducted a number of cases of asphyxiation occurred from carbon monoxide in unburned gas which had escaped. There were a few suicides, attempted suicides, and a number of accidents caused mostly by irresponsible persons. In the latter class it was difficult to decide in some cases whether they were accidents or suicides. Some of the accidents were: An intoxicated person turned on the gas and failed to light it; an infant opened the gas cocks in the absence of parents; the flame was extinguished by the boiling over of cooking food while the victim was asleep. In some cases it appeared that the gas was unknowingly turned on by brushing against the handle of the gas cock. This is likely to occur only if the tension of the spring on the gas cock is very weak. It appeared in several cases that a portable appliance was moved, which may have caused the tubing to become disconnected; but in the majority of cases in which a flexible tube was found disconnected, the acts were believed to have been intentional. If it was done accidentally, either the noise of escaping gas or the immediate unpleasant odor of the gas should have given warning that the connection was broken. If a victim of asphyxiation from carbon monoxide in unburned gas was not revived, an investigator could only conjecture the causes. When asphyxiation was caused by incomplete combustion, the condition or design of the appliance and information obtained from those who do rescue work were usually sufficient to establish the causes. In some instances investigations were hampered because those who had been poisoned as well as those who did rescue work were unable to coherently recall or relate important facts. In investigating a case of poisoning all gas-burning appliances or fixtures were carefully observed in operation or examined to ascertain if some parts were improperly designed or out of order, or if there were leaks in the gas piping which might have been a contributing cause. Only those facts pertinent to the respective cases or of unusual interest are described or mentioned. No attempt was made to determine the probable amount of carbon monoxide present when it was established that cases of asphyxia were caused entirely by escaping gas. It is well known by the public that unburned gas is very toxic. Baltimore gas contains about 20 per cent of carbon monoxide. The cases of asphyxiation reported herein are mostly those which were caused by improper combustion of the gas.

It was assumed in all the calculations given in this report that the heating value of the gas was 500 B. t. u. per cubic foot. The daily records of the Public Service Commission of Maryland and the gas company showed that variations in the heating value were usually less than 2 per cent from 500 B. t. u. The volume of gas

consumed during tests in the laboratory was corrected to the standard condition of 30 inches of mercury and 60° F. When the tests were conducted at the scene of an accident the rate of consumption of gas was measured by the meter on the premises and no corrections for barometer, temperature, or pressure of the gas were made.

Case 1. SOLID TOP FITTED TO GAS RANGE DESIGNED FOR GRATE TOP

In connection with a complaint received concerning a room heating appliance, attention was attracted by an odor emanating from the kitchen of the home, where a gas range designed for a grate top had been fitted with a solid top. The top was sold with the recommendation that it saved gas and aided in keeping the gas range clean.

By substituting a solid for a grate top on a stove designed for use with a grate top proper aeration of the flame is prevented and carbon monoxide is produced. Since all the products of combustion from the gas must escape from the opening in front of the stove, there is interference with the flow of the proper amount of secondary air [9] to the region of the flame. The flame floats around underneath the top, and at the front often licks out from under it. There is also the danger of a person being burned or having clothing set on fire when this occurs. The arrangement of the burners and the closeness of the burners to the top affect the completeness of combustion. A photograph of the range equipped with the solid top is given in Figure 2.

(*a*) Test for Carbon Monoxide.—It is rather difficult to obtain for analysis an average sample of the products of combustion from such stoves. It was decided to move this stove into the chamber where there would be no ventilation and at intervals analyze the atmosphere of the chamber and thereby determine how much carbon monoxide would be produced. Results of the test are given in Table 1.

Table 1.—*Test for carbon monoxide produced by solid top fitted on a grate-top stove*

[Tests made in unventilated room (volume=1,120 cubic feet). (Four burners lighted)]

Time in hours	Gas consumed		Analyses of room atmosphere				Carbon monoxide produced
	Cubic feet	B. t. u.	CO_2	O_2	N_2	CO	
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Cubic feet*
0	0	0	----------	20.9	79.1	----------	0
¼	16.9	8,450	0.6	19.7	79.5	0.130	1.46
½	31.9	15,950	1.3	18.0	80.4	.250	2.80
¾	46.9	23,450	1.8	17.0	80.8	.368	4.12
1	60.9	30,450	2.5	16.0	80.9	.503	5.63

[9] By primary air is meant the air that is mixed with the gas within the burner. By secondary air is meant the air which reaches the flame and takes part in the combustion of the gas after it issues from the burner.

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The tests show that the solid top caused the production of about 5.63 cubic feet of carbon monoxide per hour when the four burners under the cooking top were operated. It was fortunate that this stove was installed in a large kitchen, 12 feet 6 inches by 11 feet 6 inches by 9 feet 10 inches (volume = 1,400 cubic feet). The kitchen had three doors and one window. The door which opened to the dining room was always open, which greatly aided in ventilating the kitchen.

The following memorandum, which was received from the head of the household, gives some idea of how the people who worked in the kitchen had suffered:

Mrs. M. purchased a top plate for her gas range over a year ago. The purpose was to keep soup, etc., from spilling over the burners and to economize on gas.

For the past year Mrs. M. has often been feeling sick, especially after being in the kitchen for any length of time, as she attends to the cooking for the most part herself. She began to have frequent headaches. She also complained of her eyes aching and vision being impaired on some days. Examination of the eyes by an ophthalmologist revealed no organic trouble or any refractive defect. I could not determine exactly the cause of the headaches until recently. On several occasions after being in the kitchen Mrs. M. was taken with weak spells and had to go into another room to lie down, half fainting. The housemaid who helps with the kitchen was also suffering from headaches and sick stomach.

Since an investigation of the gas range, I am convinced that all of the above symptoms were caused by noxious or poisonous gases generated by the gas range on account of the top plate.

There are probably many gas ranges in use which have been designed for grate tops, but which have been later equipped with solid tops and it is surprising that so few complaints have been received. It is believed that the experience of the people in this case is similar to that in many other cases in which complaints are not made. The people merely tolerate the odor, headaches, and the attendant poor health that results.

Case 2. COMPLAINT REGARDING THREE APPLIANCES IN ONE HOME

A person suffered from unusual poor health almost immediately after moving into a new home. The doctor insisted that the ill health was the result of a run-down condition of the body. The person thought it might be caused by the gas appliances, three in number, all of which gave off odors. An investigation was requested. The appliances consisted of a solid-top gas range in the kitchen, one in the basement, and a water heater in the basement.

(*a*) Test of Kitchen Gas Range.—This gas range was sold equipped with a solid top. There were four burners, two in the front and two in the rear. The ports of the burners were about 1⅛ inches below the under surface of the solid top, which was too close to allow proper circulation of air to the flame. When the lids were in place the flame "floated" and at times the flame would even lick out at the front of the stove. The range had a side oven equipped with two burners and a flame spreader of inverted channel shape.

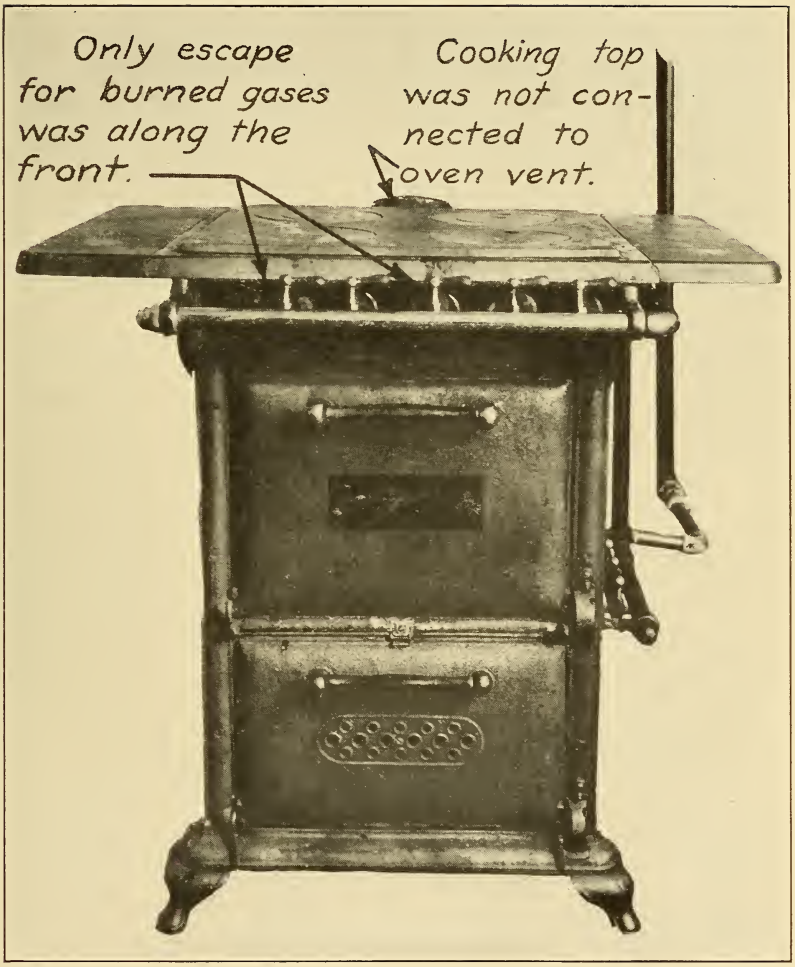


Fig. 2.—*Stove designed for a grate top which produced dangerous quantities of carbon monoxide when fitted with a solid top*

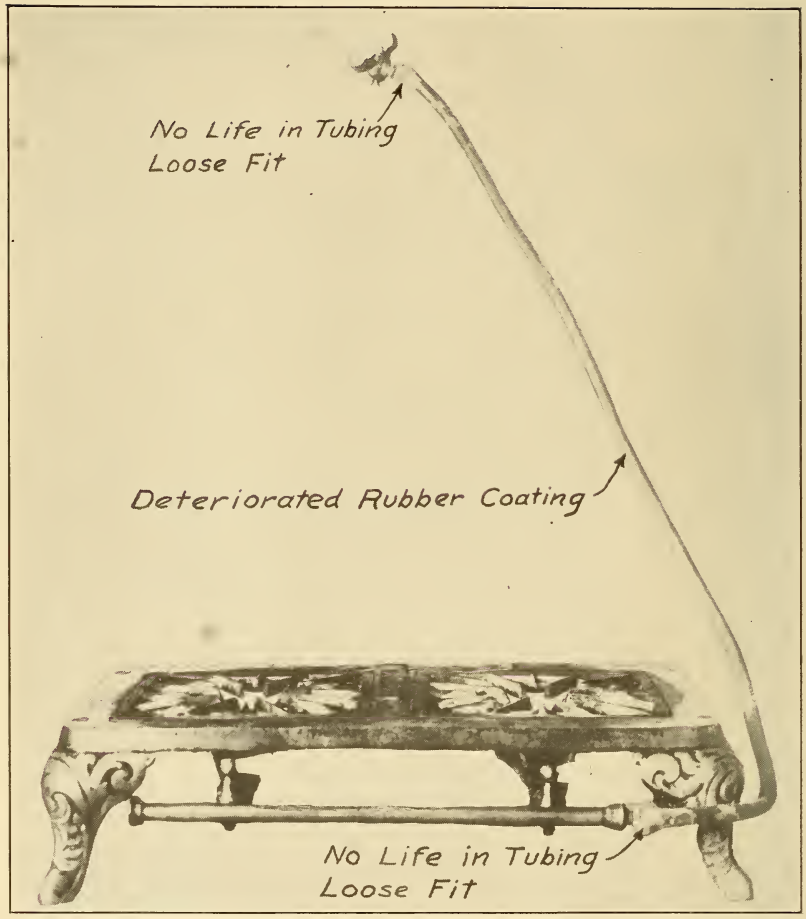


Fig. 3.—*Defective rubber tubing connecting a hot plate, the incorrectly designed burners of which are not shown*

The oven burners as well as the cooking top burners gave off an unpleasant odor. No fault could be found with the adjustment of the burners.

All four top burners and the oven burners were often operated at the same time and it was during such times that the effects were most noticeable. In testing the range all of these burners were operated for one-half hour while the four doors and the window of the kitchen were closed. The kitchen had a volume of 1,190 cubic feet.

On the day that these tests were conducted a very strong wind was blowing. However, at the end of 30 minutes the atmosphere contained 0.056 per cent of carbon monoxide and 18.6 per cent of oxygen. Even at the end of 15 minutes the kitchen atmosphere contained 0.048 per cent carbon monoxide which may cause nausea, severe headache, etc., if the subject is exposed for a sufficiently long time. When a person is standing near such a range it is likely that the air which is being breathed may contain a larger percentage of carbon monoxide.

While the kitchen was kept ventilated, the oven was operated separately, and the flue gases analyzed with the following results.

	Per cent
CO_2	3. 7
O_2	15. 8
N_2	80. 4
CO	. 016

Gas line pressure=4.7 inches.
Gas consumed per hour=68.8 cubic feet (34,400 B. t. u.)
Carbon monoxide produced per hour=0.17 cubic feet.
Air in flue gases=75.6 per cent.

The presence of 75.6 per cent of air in the flue gases indicated excellent aeration. Further tests of this range were conducted in the unventilated chamber, and are reported in a later section of this report.

(*b*) Test of Basement Gas Range.—The solid top of the range in the basement was of the same design as that of the kitchen range. The oven was below the cooking top and had two burners and an inverted channel-shape flame spreader. The air shutter of each of the oven burners was closed too far; the flames were very soft.[10] The following is an analysis of the oven flue gases:

	Per cent
CO_2	8. 0
O_2	8. 3
N_2	83. 4
CO	. 246

Gas line pressure=4.7 inches.
Gas consumed per hour=77.4 cubic feet (38,700 B. t. u.).
Carbon monoxide produced per hour=1.29 cubic feet.
Air in flue gases=39.7 per cent.

[10] By a hard flame is meant one of the type produced in the presence of much primary air. In such a flame the outlines are distinct, especially those of the inner cone; there is no yellow color, and the flame is not easily displaced by slight drafts. A soft flame is one in which there is much less primary air.

While the design of the flame spreader undoubtedly caused the formation of some of the carbon monoxide, it is believed that the type of flame and the excessive rate of consumption of gas were greater factors.

(*c*) Tests of Double-Coil Water Heater.—The diameter of the burner head of this water heater was only slightly less than the diameter of the shell, and flow of air to the outer ports of the burner was prevented. The burner was clean, but the air shutter was set for a very soft flame. The blue inner cones were just visible. The flue gases had the following composition under the conditions tested:

	Per cent
CO_2	7.8
O_2	7.5
N_2	83.2
CO	1.49

Gas line pressure=4.7 inches.
Gas consumed per hour=69.3 cubic feet (34,650 B. t. u.).
Carbon monoxide produced per hour=6.2 cubic feet
Air in flue gases=35.9 per cent.

It was fortunate that this water heater liberated such an odor that the user ventilated the basement when it was operated. The heater produced carbon monoxide at a very dangerous rate, which could have been avoided by a different design of the burner head or shell and a better type of flame. The flue gases contained 35.9 per cent of air which probably would have been ample had the distribution of air to the flame been proper.

Because there was not enough space between the burner head and the shell, the heater could be safely operated only at a greatly reduced rate of consumption. The orifice was changed to a smaller size and the air shutter was set for the proper type of flame. The flue gases had the following composition under the conditions stated:

	Per cent
CO_2	3.5
O_2	15.2
N_2	81.2
CO	.017

Gas line pressure=4.7 inches.
Gas consumed per hour=28.1 cubic feet (14,050 B. t. u.).
Carbon monoxide produced per hour=0.07 cubic foot.
Air in flue gases=72.8 per cent.

Even at this greatly reduced rate of consumption (14,050 B. t. u. per hour), which was inadequate for good service, the heater produced a small amount of carbon monoxide (0.07 cubic foot per hour), though the flue gases contained 72.8 per cent of air. The heater should not be used as designed.

The user of these appliances was shown how to operate them more safely. The kitchen range, however, was replaced by one with a

grate top after which an immediate and complete recovery of health was reported by the housewife in a grateful letter to the author of this paper

Case 3. HAZARDS FROM COMBINED EFFECTS OF IMPROPERLY DESIGNED AND ADJUSTED WATER HEATER, TWO-BURNER HOT PLATE IMPROPERLY DESIGNED, AND OLD RUBBER-COATED TUBING

Three people, two of whom were infants, were found unconscious in a kitchen where an improperly designed and poorly adjusted water heater was being operated preparatory to giving the children a bath. In addition, one burner of an improperly designed two-burner hot plate was being used to heat water in a teakettle. The hot plate was connected to the gas fixture with a piece of old rubber-coated tubing 4 feet long. The room, which had a volume of 1,270 cubic feet, had two doors and two windows, which were closed.

(*a*) Test of Water Heater.—The water heater, which was not vented, was readjusted before an opportunity was had to make tests of the products of combustion to determine the rate of formation of carbon monoxide that contributed to this case of poisoning. A sample of the flue gases from the heater when readjusted had the following composition:

	Per cent
CO_2	4.4
O_2	13.4
N_2	82.1
CO	.011

Gas line pressure=3.2 inches.
Gas consumed per hour=30.0 cubic feet (15,000 B. t. u.).
Carbon monoxide per hour=0.04 cubic foot.
Air in flue gases=64.2 per cent.

Improper combustion from this heater was caused primarily by the design of the burner head which had a diameter approximately the same as the inside diameter of the shell surrounding the copper coils and which prevented the proper aeration of the flame. Even with the proper type of flame it would be impossible to burn gas at the usual rate of consumption, which is about 45 cubic feet (22,500 B. t. u.) to 50 cubic feet (25,000 B. t. u.) per hour, with this heater without producing carbon monoxide in quantities that might be dangerous to health. Because of the design of the heater it had to be adjusted to consume only 30 cubic feet (15,000 B. t. u.) per hour, which is inadequate to heat water at the rate that is usually demanded for good service. Such heaters should be redesigned or removed from service because they can not be operated at desirable rates and with various types of flames without creating a hazard.

(*b*) Test of Two-Burner Hot Plate.—Many homes have nothing more than a two-burner hot plate for cooking purposes. The kind encountered in this case was observed in use in a number

of homes during the investigation. The burner head was made in two parts. The cap or upper portion was not made stationary and could be easily worked out of position. When the burner was lighted there were two concentric flames (an inner and outer circle of flame) and when a utensil was placed above the burner the inner circle of flame did not receive the proper supply of air, and carbon monoxide was produced. A sample of the gases containing products of combustion taken when the teakettle of 8 inches diameter was above the burner showed that 0.52 cubic foot of carbon monoxide was produced per hour. The burner was consuming 15.9 cubic feet of gas per hour and the gas pressure was 3.2 inches. The stove and the old rubber-coated tubing are shown in Figure 3.

(*c*) Test of Rubber-Coated Tubing.—On examination, the rubber-coated tubing showed that it had been in use for a long time. The rubber surface was cracked and in some places pieces had come off, exposing the fabric underneath. A leakage test of the rubber-coated tubing was made and showed that at least 2.5 cubic feet of gas per hour had been leaking, unburned, into the room. Assuming that the raw gas contained 20 per cent of carbon monoxide on that day, there was escaping 0.5 of a cubic foot of carbon monoxide per hour through the tubing. It was also observed by the person who removed the tubing that the gas leaked out where the tubing was connected to the hot plate. The ends of the tubing had very little life and fitted the connections loosely.

This case was caused by the combined effect of liberating carbon monoxide into a poorly ventilated room from three sources. As in other cases, the inquiry was made as to why this accident had not occurred at some previous time. It was claimed that these appliances were used simultaneously on a number of other occasions. However, on the day of the accident the appliances might have been operated longer, the natural ventilation might have been unusually poor, or the rubber-coated tubing might have been more loose from the fixtures.

A neighbor stated that every time the home was visited an odor was detected in the kitchen. The person using the appliances claims never to have detected an odor of any kind, which apparently indicates that one may become accustomed to the odor of raw gas or the typical odor that accompanies improper combustion from top burners and water heaters and not be conscious of it.

Case 4. COMPLAINTS REGARDING GAS APPLIANCES THAT COULD NOT BE CORRECTED

A complaint was received from one home of odors from a kitchen range and from a water heater in the basement, which had caused a person doing laundry work to lose consciousness. After the water

heater and oven of the gas range were adjusted by a trouble expert, there was still complaint of disagreeable odors.

(*a*) Test and Inspection of Gas Range.—It was observed that upon lighting the two oven burners of the gas range the odor was distinct until the oven was quite warm. The oven had a flame spreader of inverted channel shape, which caused the flame to spread from the front to the back burner. A sample of the gases emanating from the vent of the oven after it had been normally heated contained:

	Per cent
CO_2	3.5
O_2	15.1
N_2	81.2
CO	.020

Gas line pressure=3.4 inches.
Gas consumed per hour=54.9 cubic feet (27,450 B. t. u.).
Carbon monoxide produced per hour=0.15 cubic foot.
Air in flue gases=72.2 per cent.

Although the gas range was in a kitchenette, it is hardly possible that this oven could have caused headaches. The disagreeable odor, however, was objectionable. To one familiar with the appearance of a flame when an inadequate supply of air is causing the formation of carbon monoxide, it was evident that incomplete combustion occurred at that portion of the flame which was covered by the flame spreader. The spreader hindered the proper escape of the burned gases which prevented the proper supply of oxygen. The flame spreader was removed and no odor could be detected thereafter, even when the oven was first lighted.

(*b*) Inspection and Test of Water Heater.—The water heater was of a design that had caused considerable trouble because it could not be adjusted to burn the gas completely at the rate necessary to give good service. This particular heater had been adjusted to consume 31.8 cubic feet (15,900 B. t. u.). The person answering the call realized that it could not burn more gas without being extremely dangerous, yet he did not apparently realize that as he had adjusted the heater the combustion would be improper when the door was closed. A sample of the flue gases taken from the vent at the top of the heater as it had been readjusted contained:

	Per cent
CO_2	4.0
O_2	14.6
N_2	81.0
CO	.34

Gas line pressure=3.4 inches.
Carbon monoxide produced per hour=1.26 cubic feet.
Air in flue gases=69.9 per cent.

This particular type of water heater in order to give good service should be designed so that it is capable of completely burning at least

60 cubic feet (30,000 B. t. u.) per hour. The above test shows that this heater, under its very best adjustment, even when operated at a greatly diminished rate, still produced enough carbon monoxide to be extremely dangerous in a small room. It was indeed fortunate that this heater was installed in a large basement, approximately 40 feet square, or there might have been a more serious accident. Note that air in flue gases was 69.9 per cent, yet the combustion was incomplete.

The diameter of the burner is approximately the same as the inside diameter of the shell surrounding the water coils. Secondary air that gains access to the flame can flow up only through the center of the burner Carbon monoxide was produced as a result of that portion of the flame next to the shell not being properly aerated. It could be seen that the flame impinged against the shell.

Case 5. CARELESS OPERATION OF ROOM HEATER

A person made an improvised bed in the office of a factory and before retiring for the night placed a basin of water over the vent of a gas heater. It was believed that the steam from the water assisted in heating the room. Six and one-half hours after retiring the person was found almost lifeless. In order to restore proper breathing the pulmotor was used for two hours and an inhalator for one-half hour. The man remained unconscious for four days and it required eight days more for sufficient recovery to permit his discharge from the hospital. The room in question had a volume of 1,770 cubic feet. Its two doors and one window were closed.

(*a*) Description of Room Heater.—The heater was of an unusual design, resembling an oil stove equipped with a large Bunsen burner. Figure 4 shows a general view of the heater with the basin in the same position as when the person was found. The opening at the top of the heater, which provides for the escape of the products of combustion was 4.6 inches in diameter.

(*b*) Tests to Determine the Condition Within the Room.—A tube through which samples of the room atmosphere could be drawn was extended into the room. The end of the tube was 7 feet from the heater and 30 inches from the floor to correspond with the location of the person's head. The heater was lighted and the basin filled with water was placed on top of it, as shown by Figure 4. The basin completely covered the opening at the top of the heater, which was provided for the escape of the products of combustion. Results of tests of the room atmosphere are given in Table 2.

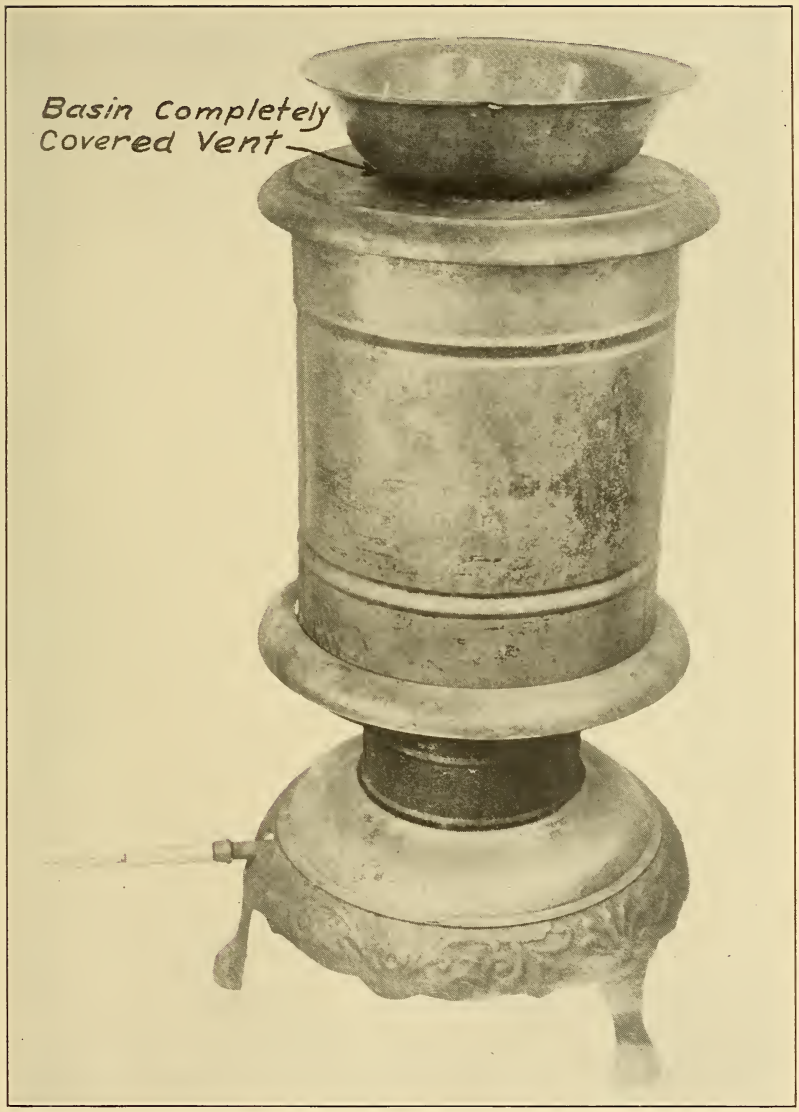


FIG. 4.—*Basin, placed on vent of an appliance, which nearly caused death*

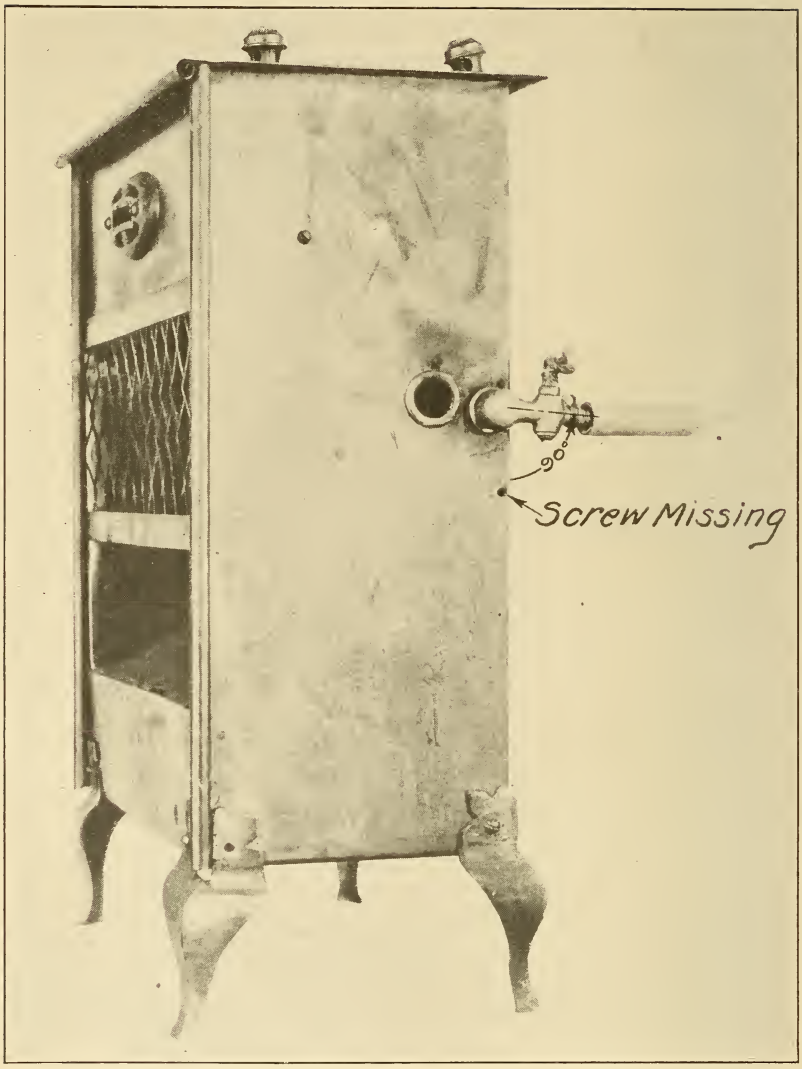


FIG. 5.—*Yellow flame heater incorrectly blamed for a death which was actually caused by raw gas*

TABLE 2.—*Test of room atmosphere with basin on top of heater*

Time in hours	Total gas consumed		Analyses of room atmosphere				Oxygen in room (per cent of normal)
	Cubic feet	B. t. u.	CO_2	O_2	N_2	CO	
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0	0	0	0.0	20.9	79.1	0	100.0
½			.2	20.5	79.1	.110	98.1
1			.3	20.1	79.4	.166	96.2
2			.4	20.0	79.4	.172	95.7
3			.5	19.9	79.3	.218	95.2
4 [1]	121.0	60,500	.1	20.3	79.3	.236	97.1

[1] It was necessary to enter the room twice after taking the 3-hour sample, which evidently resulted in changing the condition of the atmosphere.

It is of interest that the person remained alive for six and a half hours in an atmosphere that contained so much carbon monoxide. Because of the fact that the man was inactive, probably asleep soon after lighting the heater, the rate of poisoning was not as rapid nor the effects as serious as if he had been active until overcome. The adjustment of the burner may have been better at the time of the accident or the gas may not have been turned on full, either of which might have caused less carbon monoxide to have been produced. It will be noted that the ventilation of the room was good even though closed. After the heater had been burning for three hours and about 90.0 cubic feet of gas had been consumed the room atmosphere contained 19.9 per cent oxygen (95.2 per cent of normal).

Because of its construction there was some question whether combustion would be complete when the heater was operated normally. When the air shutter was set for a blue flame the heater produced only 0.04 cubic foot of carbon monoxide per hour.

This case is clearly one of ignorance. Many people do not realize that a flame can not be trapped without interfering with proper combustion, that when improper combustion occurs carbon monoxide is produced, and that carbon monoxide is a poisonous gas even in small concentrations. Furthermore, when an odor is detected from an appliance, the consumer will generally incorrectly blame the quality of the gas. The public rarely questions the design of the appliance, its manner of installation, adjustment, or cleanliness of the parts, and especially the manner of operation by the user. Manufacturers of appliances should design the vent so that the placing of a utensil over it will not interfere with the free escape of the products of combustion.

Case 6. ASPHYXIATION FROM ESCAPING GAS WITH WINDOW OPEN

A person was found dead in a room which contained a yellow-flame heater from which the flexible tubing was disconnected and gas was flowing from it, the gas having been turned on at the wall connection.

The room had a capacity of 1,400 cubic feet and had two windows and one door. One window was down about 18 inches from the top. When found, the open end of the hose was about 12 inches from the person's head and about 6 inches from the heater. The heater was located between the two windows.

The heater was of the copper reflector type. A missing screw permitted a displacement of the burner. Inspection of the heater revealed that much carbon was deposited on the reflector back, showing that the heater had been operated at some time with the burner in an improper position. Figure 5 is a view of the heater with the burner turned 90° from the proper position. Figure 6 shows a photograph of the copper back. The places where the flame impinged against the copper back when the burner was turned downward are plainly visible.

Test of Heater.—The heater consumed 36.8 cubic feet of gas per hour at a pressure of 3 inches; it was designed with a vent in the back so that it could be connected to a flue. The products of combustion were sampled at this opening. When the burner was in its normal position, only 0.05 cubic foot of carbon monoxide was produced per hour. When the burner was turned down through 90° from the proper position so that the flame impinged against the copper back, only 0.04 cubic foot of carbon monoxide was produced per hour. When the burner was turned up through 90°, again causing the flame to impinge and lap against the copper back, only 0.01 cubic foot of carbon monoxide was produced per hour. In all of these tests the quantities of carbon monoxide obtained amounted to only traces in the products of combustion. These results clearly show that this yellow-flame heater was not at all dangerous, but that death was caused by the direct escape of gas from the tubing which had been accidentally or intentionally disconnected from the heater.

The facts in this case, and others which will be mentioned in this paper, indicate that when a flame impinges upon a metal surface, carbon monoxide is not necessarily produced even though carbon is deposited. The liberation of carbon monoxide depends largely upon whether air has free access to the flame.

Case 7. HEADACHES CAUSED BY A NEW RADIANT HEATER

A complaint was received regarding a new heater which had five radiants of the average size and was connected to the gas line with flexible corrugated metal tubing.

Tests of Heater.—When the heater was lighted and the room was darkened a long soft flame could be seen streaming from the top of the radiants showing that too much gas was being supplied. The gas pressure at the heater was 3.4 inches, the rate of consumption of gas was 34.4 cubic feet (17,200 B. t. u.) per hour,

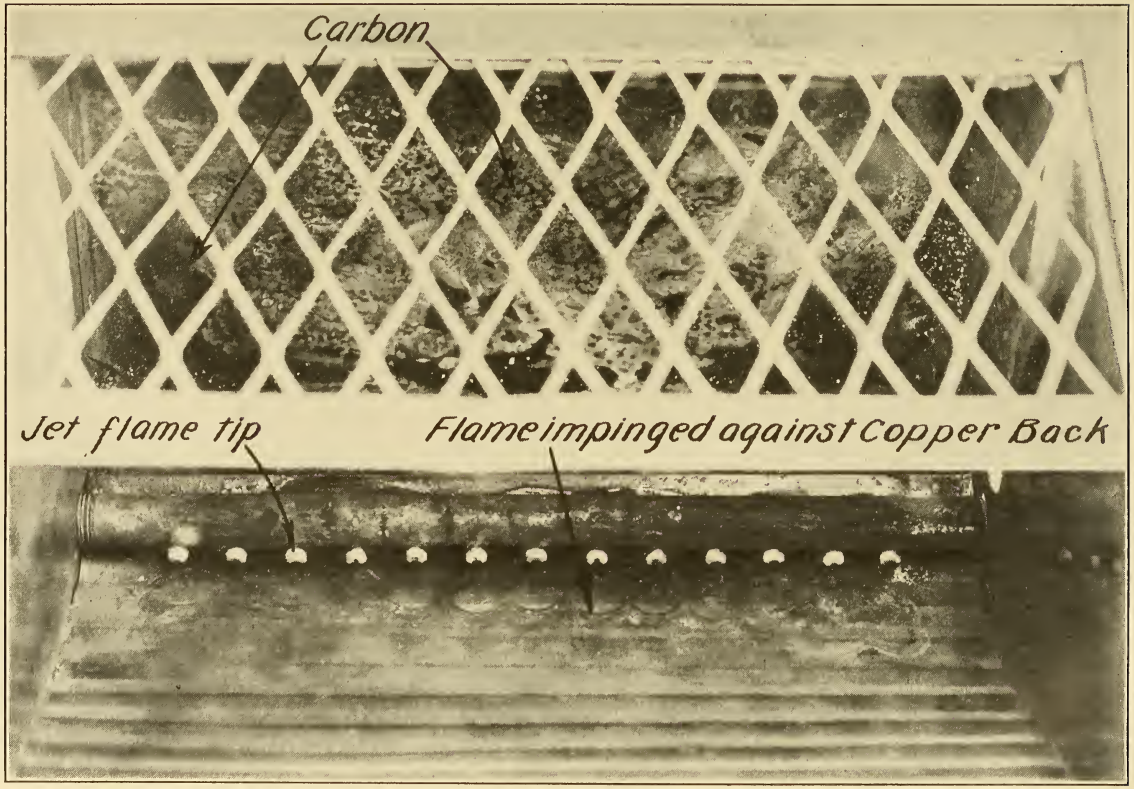


Fig. 6.—*Copper reflector of "yellow flame heater" shown in Figure 5. Note the carbon*

and carbon monoxide was being produced at the rate of 0.88 cubic foot per hour. In addition, the flexible tubing, though in use only a short time and supposedly new, was leaking 0.62 cubic foot of gas per hour. On the basis of the gas containing 20 per cent of carbon monoxide there was leaking into the room 0.13 cubic foot of carbon monoxide per hour. The total amount of carbon monoxide liberated into the room from the heater and the leak from the tubing was about 1.01 cubic feet per hour.

The burner was designed without an air shutter. The owner of the heater claims it was being used as purchased. The adjustable orifice, which had not been touched, was set for the wide-open position, which allowed gas to flow at an excessive rate. Each radiant was supplied with an average of 3,440 B. t. u. per hour.

When the orifice of a heater is too large, good combustion may not be obtainable even when the gas cock is closed to permit the use of only a moderate amount of gas, because the pressure at the orifice is so reduced that the gas stream does not have enough energy to inject the amount of air required for a proper type of flame. Tests of this heater made at pressures of 1 and 2 inches gave the following results:

Gas pressure (inches)	Gas consumed per hour			Carbon monoxide produced per hour (cubic foot)
	Cubic feet	Total B. t. u.	B. t. u. per radiant	
1	17.2	8,600	1,720	0.56
2	24.9	12,450	2,490	.97

The flame was quite soft at both pressures. There was some streaming of the flame from the top of the radiant at 2 inches pressure (2,490 B. t. u. per radiant). The smaller rate of production of carbon monoxide at 3.4 inches than at 2 inches pressure was probably caused by the combustion being more nearly completed in the free air outside the radiant.

The complaint of poisoning from improper combustion was primarily caused by the manufacturer having equipped the appliance with too large an orifice. Some manufacturers aim to design the orifice of their heaters so large that they can be used with manufactured or natural gas of any heating value. Such practice is very dangerous. If radiant heaters of this type are equipped with adjustable orifices the range of adjustment must be very narrow, because of the narrow range within which they operate satisfactorily.

It can also be claimed that this case could have been avoided if the dealer had set the adjustable orifice so that it would pass the proper amount of gas at the average pressure supplied in Baltimore.

Since it requires unusual experience for one to decide when a radiant heater is designed, installed, or adjusted so that it can be operated with reasonable safety, manufacturers should endeavor to design their heaters so that dealers or gas fitters are not likely to install or adjust them improperly.

Case 8. FATAL ASPHYXIATION OF TWO PEOPLE IN A CLOSED BEDROOM BY A RADIANT HEATER

Two people are known to have retired about 1 a. m. They were found dead in bed 36 hours later. A radiant heater of 10-radiant size was still burning. The bedroom was rather large (2,000 cubic feet) and had five windows and two doors, all of which were closed. An inspection of the heater showed it would light properly, that there were no obstructions on the burner tips, such as broken radiants, and that the radiants were free from soot. It was observed that if the room was made slightly dark the flame could be seen streaming from the top of all the radiants. The very slight odor that could be detected was not considered to be disagreeable.

(*a*) Results of Tests of Room Atmosphere.—The room was closed as when the two persons were found. A tube was run into the room and terminated 30 inches from the floor and about 10 feet from the heater and on the opposite side of the room to correspond with the location of the heads of the two persons. The gas heater was lighted and samples of the atmosphere were drawn from the room at various intervals. In Table 3 are given the analyses of the room atmosphere.

Table 3.—*Test of 10-radiant heater in a closed bedroom*

[Volume of room = 2,000 cubic feet]

Time in hours	Total gas consumed		Analyses of room atmosphere				Oxygen in room (per cent of normal)
	Cubic feet	B. t. u.	CO_2	O_2	N_2	CO	
			Per cent	*Per cent*	*Per cent*	*Per cent*	
0	0	0	0	20.9	79.1	0.000	100.0
½			0.4	20.3	79.2	.043	97.1
1			1.1	19.1	79.7	.073	91.4
2			1.3	18.7	79.9	.077	89.5
3	155	77,500	1.5	18.5	79.9	.093	88.5

Note.—Gas line pressure=4.2 inches.

The samples of the room atmosphere were taken from the windward side of the room. The direction of the wind was the same as when the people were asphyxiated. During the tests there was a brisk wind, but the Weather Bureau reports that the wind was very light during the time that the persons were subjected to the poisonous atmosphere. Owing to variations of wind velocity and direction

one never knows how well the conditions have been duplicated when it is desired to reproduce what occurred.

A sample of the gases containing products of combustion, taken above the heater when the room was well ventilated, showed that the heater produced carbon monoxide at the rate of 1.79 cubic feet per hour. This test showed that if there had been absolutely no ventilation, the atmosphere of the room would have contained 0.266 per cent of carbon monoxide at the end of three hours. It will be observed that the heater was consuming 52 cubic feet per hour, or 5.2 cubic feet per radiant per hour, which is 2,600 B. t. u. per hour per radiant—a very excessive rate of consumption. Time would not permit tests to determine how much gas this heater could safely burn in the condition in which it was found, or how much carbon monoxide would have been produced if the heater had been as clean as when new.

(*b*) Discussion of Construction of Heater.—The heater had not been altered by the users. The burner was made without an air shutter and the orifice was fixed, making it difficult for the heater to be tampered with. The appearance of the blue cone of the flames indicated that something was causing a reduction of the injection of primary air to a greater extent than with a new burner. The blue cones were soft and flimsy.

The gaseous mixture for each radiant issued from a burner tip comprised of a number of bars arranged to form narrow slots in which there was considerable lint. On the surface of the sides of the bars that formed the slots was a thin layer of foreign material, while on their lower edge the material adhered unevenly and it was at this point that the slots were closed most. The bars were made of an alloy of copper and nickel. The material adhering to the bars of several tips was removed. The analysis was as follows:

	Per cent
Copper	33. 0
Nickel	25. 0
Sulphur	21. 0
Iron	5. 0
Oxygen	Indicated.
Undertermined	Balance.

It was believed before this analysis that the adherent material might be largely the result of oxidation, caused by the high temperature to which the tips are subjected. The fact that such a large percentage of sulphur was obtained shows that the bars were gradually corroded by traces of the sulphur gases which could not be removed in the process of manufacture. The scale on the sides of the bars was quite even.

An examination of the records of the Public Service Commission of Maryland showed that the gas is exceptionally free from sulphur.

It is a rule of the commission that the sulphur content of the gas must not exceed 30 grains per 100 cubic feet. This is the usual requirement enforced by other State commissions throughout the United States.

The heater had been in service about five years. It is believed that the lint and corrosion which clogged the slots was the accumulation from years of service. Burner tips for use in radiant heaters that consume manufactured gas should not be made from copper alloys because it is impracticable to supply manufactured gas completely free from sulphur. Furthermore, the users should be advised to clean the lint and other foreign material from the burner tips from time to time.

Case 9. SERIOUS ILLNESS OF FIVE PEOPLE IN POORLY VENTILATED BEDROOMS CAUSED BY AN IMPROPERLY INSTALLED AND ADJUSTED RADIANT HEATER

Before five people retired for the night a four-radiant heater was lighted in one of two communicating bedrooms. Fortunately, several hours later these people were awakened. All were seriously ill; they suffered with severe headaches, vomited, and were so weak they could not walk.

(*a*) Inspection of Heater and Manner of Installation.—The heater was connected to a gaslight fixture at the ceiling by new flexible metal tubing 9 feet 10 inches long. There were no gas leaks. It was observed on lighting the heater that the flame was improper for heaters of this design, there being an insufficient injection of air. At first observation it was believed that the air shutter was closed too far, it being only about one-half open. When the air shutter was completely opened, there was no noticeable change in the appearance of the flame, which proved that the air shutter setting had not affected the performance of the heater. The design of the injecting tube of the burner could be improved. The radiants were clean and free from soot. The heater did not give off odors.

A sketch showing the manner of installation of the heater and a section of the stiff bracket to which the heater was connected is shown in Figure 7. The resistance to flow through the bracket reduced the gas pressure and caused the fitter to insert an orifice that would pass the volume of gas required to make the radiants glow to the top.

(*b*) Tests of Heater.—It was apparent that the heater was improperly installed and tests were made at the home to determine the condition of operation. The gas-line pressure was 2.8 inches, and the pressure at the inlet to the flexible tubing was 1.3 inches, showing a loss of 1.5 inches of pressure in flowing through the gaslight fixture. Further, the pressure at the outlet of the flexible tubing was 1.05

inches, showing a loss of 0.25 inch of pressure through the tubing, which makes a total loss of pressure of 1.75 inches between the gas line at the ceiling and the connection to the heater. Under this condition of operation the heater was consuming 15.7 cubic feet of gas (7,850 B. t. u.) per hour and was producing 1.32 cubic feet of carbon monoxide per hour. It will be noted that this four-radiant heater was liberating 1,915 B. t. u. per radiant per hour. The heater was then taken to the laboratory, where the same condition of operation

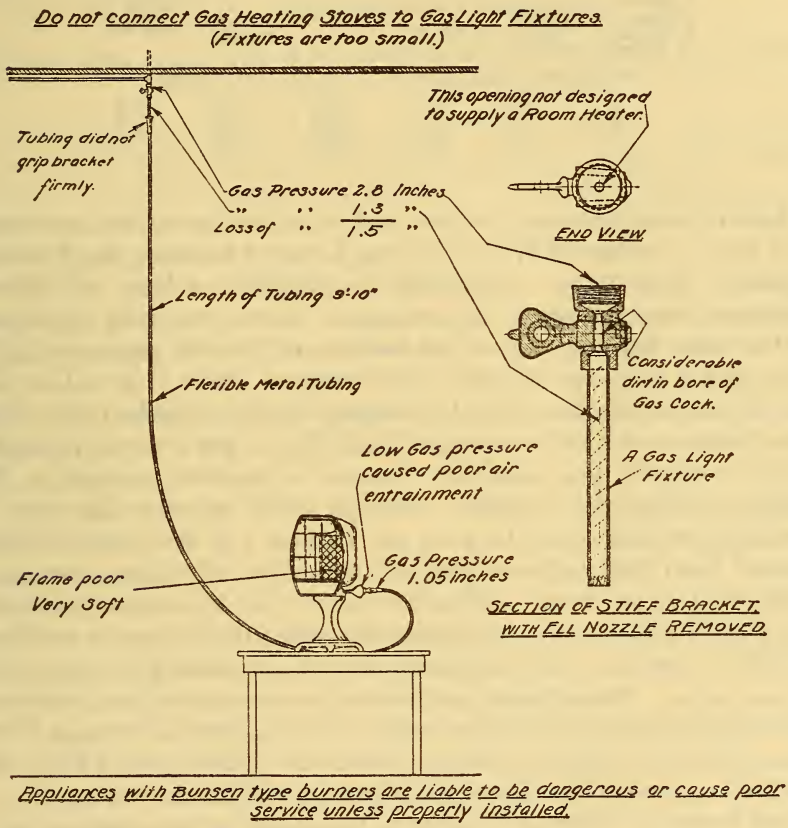


FIG. 7.—*Incorrect method of installing a room heater*

was duplicated and the products of combustion were again tested. The laboratory test showed that 1.29 cubic feet of carbon monoxide was being produced per hour, which was an excellent check of the test made in the home.

It was evident from the rate of flow of gas in the above tests that the size of the orifice was much larger than that with which the heater was originally equipped. To learn how much carbon monoxide would be produced if the heater as tested above were connected to

the proper kind of fixture and operated at normal pressure, which would, of course, allow the flow of an excessive volume of gas, the tests of Table 4 were made.

TABLE 4.—*Test of portable four-radiant heater with large orifice, connected to proper fixture*

Gas pressure in inches		Gas consumed per hour			CO produced per hour (cubic feet)
At entrance to flexible tubing	At outlet of flexible tubing	Cubic feet	Total B. t. u.	B. t. u. per radiant	
1	0.8	12.8	6,400	1,600	0.52
2	1.7	19.0	9,500	2,375	1.21
3	2.5	23.8	11,900	2,975	.49
4	3.4	27.9	13,950	3,490	.25

It is of special interest to note that when the heater was operated at 3 inches pressure (2,975 B. t. u. per hour per radiant) and 4 inches pressure (3,490 B. t. u. per hour per radiant) a large soft flame streamed from the top of the radiants. There was some streaming of the flame from the top of the radiants at 2 inches pressure (2,375 B. t. u. per hour per radiant). Referring to Table 4, it will be observed that of the four tests the largest amount of carbon monoxide was produced at 2 inches pressure (2,375 B. t. u. per hour per radiant), which is slightly less than that obtained at an inlet pressure to the flexible tubing of 1.3 inches. At this latter pressure the rate of consumption was 1,915 B. t. u. per radiant and the flame did not stream from the radiants, yet 1.32 cubic feet of carbon monoxide was produced per hour. These tests show that this heater produced the largest amount of carbon monoxide when the flame was confined within the radiant, and that the greater the streaming the more safe it was to use. Manufacturers of radiant heaters and others, however, have been of the opinion that with the same type of flame it is far more serious to operate a heater when the flame streams from the radiant than when the flame is completely within the radiant.

(*c*) FURTHER TEST OF HEATER.—The orifice, which was decidedly too large, was removed and replaced by a smaller one. When again tested, with a pressure of 2.3 inches at the orifice, 0.31 cubic foot of carbon monoxide was produced per hour. Although the heater still produced carbon monoxide at a rate that might cause illness, it is evident that the severe poisoning in this case would not have occurred if it had been installed with the proper gas connection and orifice.

The burner of this heater was very susceptible to flash back if the flame was of the hard type (large primary air injection). The manufacturer probably intended that the air shutter should be set so that

the flame would not be likely to flash back. When this was done the flame was too soft and sufficient secondary air could not enter the small and semiclosed radiant. To completely eliminate the formation of carbon monoxide and to make the heater reasonably safe, the rate of consumption per radiant would have had to be greatly reduced. The radiants should have been larger to permit the access of secondary air, or the injecting tube should have been designed to secure greater injection of primary air, in which case the burner tip would have had to be redesigned to eliminate flash back.

Case 10. ONE DEAD AND FOUR UNCONSCIOUS PERSONS IN CLOSED BEDROOM HEATED BY RADIANT HEATER

A radiant room heater and a wall-bracket gaslight were lighted when three children were put to bed about 9 p. m. When the parents went to bed in the same room about 11 p. m. the children were ill and were given castor oil. About 12.30 a. m. the mother became ill. This is the last incident any of them remembered.

The five persons were found unconscious about 11 a. m. The door and all windows were closed and the gaslight and room heater were burning. It is claimed there was no odor of gas in the room. The volume of the room was 1,790 cubic feet. The heater and light were turned off, the windows were raised, and the pulmotor was summoned. The youngest child, 2 years old, died about 4 p. m. The others were revived.

(*a*) Condition of Room Heater.—It was observed that carbon was deposited on the tips of the cones of the radiants and that carbon clogged the ports of the burner. The fact that carbon clogged the ports indicates that the heater had been operated at some time under the flash-back condition. It is doubtful if it was being operated in this manner at the time of the accident. The air shutter of the burner was about 40 per cent closed.

Though it was claimed there were no odors of gas in the room the meter showed a leakage of about 0.5 cubic foot per hour. Five very small leaks were found, three of which were in the room. The two cocks at the wall fixture leaked slightly and a larger leak occurred at the coupling to the burner of the room heater. There was not enough leakage of gas to contribute greatly to the accident.

(*b*) Operation of the Room Heater in the Closed Room.—To ascertain the probable condition of the room atmosphere while the occupants were exposed, the door and windows were closed and the heater was operated in the same position as when the accident occurred. The atmosphere of the room was sampled at a point on the bed to correspond to the location of the occupants. The analyses of the room atmosphere taken at intervals of one hour are given in Table 5. It will be observed from this table that the percentage

of carbon monoxide in the room atmosphere was practically constant after the heater had been operated about three hours. At the end of six hours the atmosphere contained 0.08 per cent of carbon monoxide. According to published literature 0.08 per cent of carbon monoxide, if breathed for several hours, will cause about 60 per cent of the hæmoglobin of the blood to become saturated, and unconsciousness will result. It has been stated that infants are more susceptible to carbon monoxide poisoning than adults, which may account for the death of the 2-year-old child.

The ventilation of the room was good, though windows and door were closed. Ventilation was undoubtedly augmented by an opening in one of the windowpanes, which was about 6 inches square. The lowest oxygen content of the room during the tests was 19.1 per cent which is 91.4 per cent of normal.

TABLE 5.—*Analyses of atmosphere in closed room during operation of a four-radiant heater*

[Volume of room=1,790 cubic feet]

Time in hours	Analyses of room atmosphere				Oxygen in room (per cent of normal)
	CO_2	O_2	N_2	CO	
	Per cent	*Per cent*	*Per cent*	*Per cent*	
0	0.1	20.8	79.1	0.00	99.6
1	.9	19.9	79.1	.038	95.2
2	.8	19.4	79.7	.060	92.8
3	1.4	19.3	79.2	.073	92.4
4	1.3	19.2	79.4	.076	91.9
5	1.5	19.1	79.3	.081	91.4
6	.9	19.3	79.7	.080	92.4

NOTE.—Rate of consumption of gas=18.5 cubic feet per hour (9,250 B. t. u.); gas-line pressure=3.4 inches of water.

It is of interest to know whether the amount of oxygen that was consumed by the occupants of the room was of vital importance. A normal man at rest inhales about 500 cubic centimeters (30.5 cubic inches) of air per inspiration. When expired the exhalation contains by volume: Nitrogen, 79.0 per cent; oxygen, 16.02 per cent; carbon dioxide, 4.38 per cent.[11] An adult makes about 18 respirations per minute. If it is assumed that the three children consumed oxygen at a rate equivalent to one and one-half adults, the five occupants were inhaling approximately 67 cubic feet of air per hour. If the exhalation contained 16 per cent of oxygen, the volume of air from which the oxygen was completely removed by the occupants was about 16 cubic feet per hour.

The room heater was consuming about 18.5 cubic feet of gas per hour. If we assume that the gaslight was burning about 5 cubic feet per hour, there was being consumed per hour a total of 23.5 cubic feet of gas. From an analysis of the gas it was computed that the oxygen

[11] Textbook of Physiology, Howell, 9th ed., p. 666.

from 4.14 cubic feet of air is required to completely burn a cubic foot of gas. Therefore, to burn 23.5 cubic feet of gas, oxygen from 97.3 cubic feet of air was required. Since the occupants of the room only required the oxygen from about 16 cubic feet of air per hour, they used only about 16 per cent as much oxygen as the burning gas. After making allowance for the natural ventilation which occurred, it is believed that the oxygen content of the atmosphere was not seriously reduced by the occupants of the room.

(*c*) Further Tests of Heater.—A sample of the flue gases from the heater was obtained for analysis when the room was properly ventilated. This test showed that the heater was normally producing 0.79 cubic foot of carbon monoxide per hour when the gas pressure was 3.4 inches and the rate of consumption of gas was 18.5 cubic feet per hour (2,310 B. t. u. per radiant).

The heater was moved to the laboratory where a series of seven tests was made. In Table 6 are given the results. When the radiants were removed the supply of secondary air to the flame was not restricted and the combustion was complete. When the burner was cleaned the combustion was greatly improved. Replacing the old radiants with improved ones gave better combustion. Reducing the rate of consumption of gas also reduced the rate of formation of carbon monoxide. When about 1,600 B. t. u. per hour per radiant was being liberated only a trace of carbon monoxide was formed.

In this case the design of the burner and the radiants combined to cause insufficient aeration of the flame. The accident would probably not have occurred if the design of the injecting tube of the burner had allowed for a greater injection of primary air, if the burner tips had been designed to avoid too ready flash back of the flame, if the radiants had been more openly constructed to permit the access of a greater amount of secondary air to the flame, and if the heater had been operated at a smaller rate of consumption of gas.

Table 6.—*Laboratory tests of four-radiant room heater*

Kind of test	Gas pressure	Rate of consumption			Carbon monoxide produced per hour
		Cubic feet per hour	B. t. u. per hour		
			Total	Per radiant	
	Inches				*Cubic feet*
Heater as received from home	3.4	17.8	8,900	2,225	0.60
Heater as received, with radiants removed	3.9	17.7	8,850	2,210	.00
Heater as received, with new radiants	3.4	17.9	8,950	2,240	.27
Heater with ports cleaned and old radiants	3.7	16.3	8,150	2,040	.35
Heater with ports cleaned and new radiants.	2.0	12.7	6,350	1,590	(1)
	3.4	15.7	7,850	1,960	.11
	4.0	17.8	8,900	2,225	.15

[1] Trace.

Note.—New radiant was more openly constructed.

Case 11. TEST OF ROOM HEATER PURCHASED FROM AND ADJUSTED BY APPLIANCE DEALER

Several incidents during the investigation suggested the idea of learning, if possible, the practice of gas-appliance dealers when selling appliances. It was decided to appear in the guise of an uninformed customer to make a purchase of an appliance for test. The author was shown several types of appliances, one of which was equipped with a gas mask "to absorb the fumes." It was explained that none of the radiant heaters needed a gas mask, since no radiant heater ever gave off fumes. All the different types were, of course, highly recommended, including one of the blue-flame type which was purchased for test. The salesman adjusted the appliance in the store and stated it could be taken home, connected, and used with perfect satisfaction without further attention.

Resting on the burner of this appliance was a tray filled with "potters' ware stilts" (waste material from potteries) which became heated, glowed, and served as "radiants." The tray was placed so close to the burner that the flame could be observed only with difficulty. The flame impinged upon the pieces of pottery and wound its way up through them. At the larger rates of consumption the flame could be seen to burn at the top of the "radiants." The position of this tray so close to the burner prevented the proper aeration of the flame and caused the production of carbon monoxide and odors. The products of combustion escaped through a vent at the rear of the top of the heater.

Analyses of samples of the flue gases taken at the vent at the tod of the heater are given in Table 7.

TABLE 7.—*Test of burner with tray of refractory material on burner*

Gas line pressure in inches	Gas consumed per hour		Analysis of flue gases				Carbon monoxide produced per hour
	Cubic feet	B. t. u.	CO_2	O_2	N_2	CO	
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Cubic foot*
2	14.8	7,400	2.7	16.3	80.9	0.102	0.27
3	19.3	9,650	3.3	15.1	81.4	.227	.62
4	22.8	11,400	4.3	13.7	81.8	.171	.44

It is of interest to know that the salesman had adjusted this heater for what is generally considered the proper type of flame. The blue inner cone of the flame was very distinct. The tests show that the heater was a carbon monoxide producer at any rate of consumption. At 3 inches pressure the gas consumption was 19.3 cubic feet per hour and carbon monoxide was produced at a rate of 0.62 cubic foot per hour.

It is evident that if this heater were to be used in a poorly-ventilated living room of the average size, it would cause the average person to develop a headache in about an hour. In a poorly-ventilated bedroom more serious results could be expected.

Case 12. IMPROPERLY DESIGNED AND POORLY ADJUSTED UNVENTED WATER HEATER OPERATED IN SMALL BATHROOM

On the first occasion that a new water heater in a bathroom was used a person was found unconscious upon the floor 45 minutes after entering the room and lighting the heater. During this time the door was opened twice. There was one loosely-fitted window in the bathroom which was closed. Figure 8 shows a sketch of the bath-

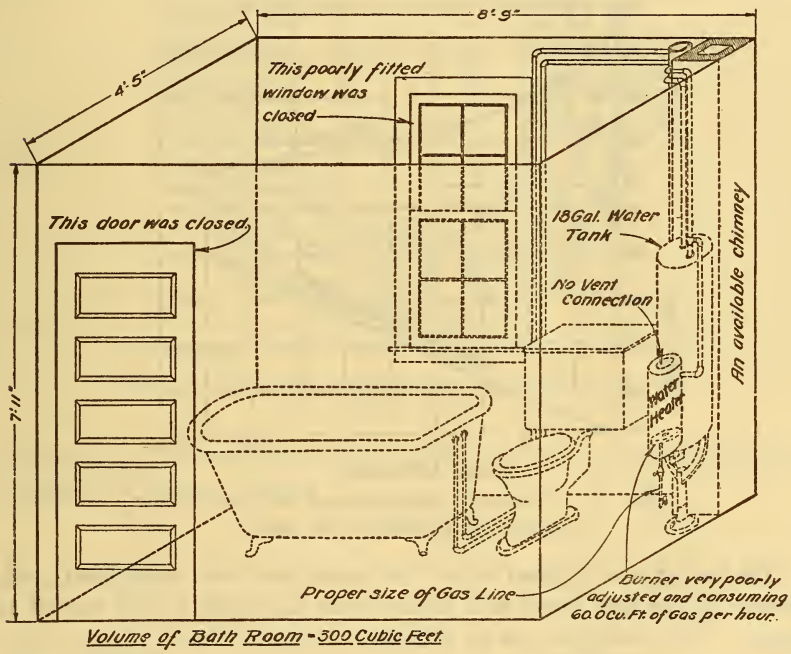


FIG. 8.—*Bathroom with unvented water heater adjacent to available chimney*

room which had a volume of only about 300 cubic feet.

Tests were made to determine the probable condition of the atmosphere in the room during the 45 minutes the person was exposed. Samples of the room atmosphere were taken after 10, 20, 30, and 45 minutes. After the 10-minute sample was taken the door was opened and a person entered the bathroom and again came out. This was repeated after the 20-minute sample was taken to correspond with what occurred while the person was exposed. The essential results of the tests are shown in Figure 9. Note the rapid rate at which

the oxygen content of the bathroom atmosphere was reduced. As the oxygen content was being depleted the extent of smothering of the flame and the rate of formation of carbon monoxide were increased. This is shown by the slopes of the oxygen and carbon monoxide curves of the figure.

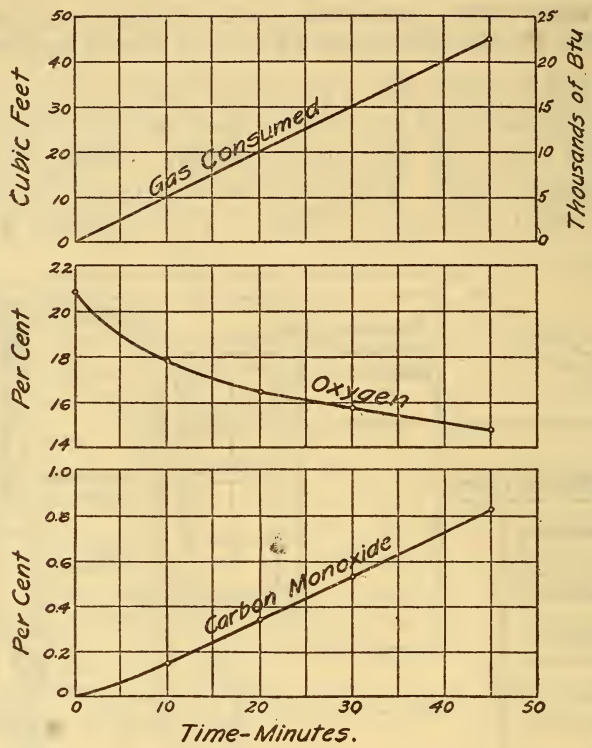


FIG. 9.—*Changes in atmosphere of bathroom during operation of unvented water heater*

The heater was lighted when the room was well ventilated, and a sample of the flue gases was taken from the vent at the top of the heater. The analysis was as follows:

	Per cent
CO_2	9.3
O_2	6.3
N_2	84.1
CO	.27

Gas line pressure = 3.5 inches of water.
Gas consumed at rate of 60 cubic feet per hour (30,000 B. t. u.).
Carbon monoxide produced per hour = 0.86 cubic foot.
Air in flue gases = 30.1 per cent.

Three things were wrong: (1) The orifice supplied with the heater was too large. (2) The air shutter of the burner had not been adjusted for the proper kind of flame. The flame was large and soft because there was not enough primary air. (3) The burner was not

properly designed. Figure 10 illustrates the design of the burner head. There are three concentric rows of ports. If a water heater having a burner of this design is operated at the rate of consumption required for good service, the middle row of ports does not receive the necessary supply of secondary air and carbon monoxide is produced, even when the air shutter is properly adjusted.

(*a*) Final Adjustment of Heater.—A smaller orifice was inserted and the air shutter was set for the proper kind of flame. The flue

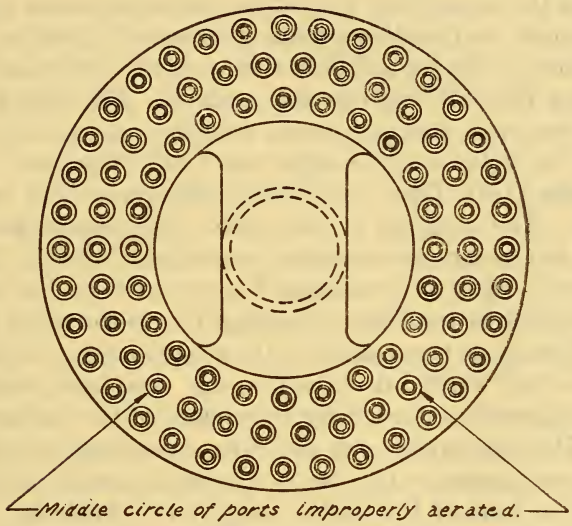


Fig. 10.—*Improper arrangement of ports of a water heater burner*

gases were again sampled from the vent at the top of the heater and the analysis was as follows:

	Per cent
CO_2	6.8
O_2	9.7
N_2	83.4
CO	.014

Gas line pressure=3.3 inches of water.
Gas consumed at rate of 46.3 cubic feet per hour (23,150 B. t. u.).
Carbon monoxide produced per hour=0.05 cubic foot.
Air in flue gases=46.4 per cent.

The final test of the heater showed that little carbon monoxide was produced when the burner was properly adjusted and the oxygen content of the bathroom was normal (20.9 per cent). It is unsafe to install any appliance that consumes gas at such a large rate in such a small room, especially if the appliance is unvented. If an unvented appliance is poorly designed or improperly adjusted, it may require only a short time to create a very serious condition. Also, even though the appliance may be well adjusted, if operated long enough,

the oxygen content of the room may be diminished to such an extent that the flame will be partially or totally smothered with the result that carbon monoxide is produced. In this case the heater was set almost against a chimney. Had a flue connection been made the accident would almost certainly have been avoided.

Case 13. AN IMPROPERLY ADJUSTED AND DIRTY WATER HEATER

In a six-room semidetached house, two people were overcome in the rear room of the second floor by carbon monoxide from a water heater in the basement, and another person working in the kitchen was made ill. The door at the top of the stairway to the basement was open, allowing free flow of fumes to the upstairs. The rear door of the basement was open and one person working near the door was not affected. The volume of the cellar was 5,200 cubic feet.

Inspection and Test of Water Heater.—The burner was very dirty. The clogging of the ports with foreign material was equivalent to closing approximately one-third of them. The burner had 85 ports. Most of the clogged ports were on one side of the burner, resulting in the flame extending far up the other side of the heater. There were two baffles on the copper coils; the lower one by some means had worked down within one turn from the bottom of the coils and greatly retarded the movement of the products of combustion. The gas orifice was too large, resulting in the flow of a volume of gas approximately twice the rated capacity of the heater. The results of tests of the heater are given in Table 8.

Table 8.—*Tests of water heater*

		Before cleaning and readjustment	Final adjustment
Gas consumed	cubic feet per hour	96.7	48.4
	B. t. u. per hour	48,350	24,200
Analysis of flue gases:			
CO_2	per cent	6.6	9.4
O_2	do	2.0	6.1
N_2	do	82.8	84.5
CO	do	[1] 8.6	.00
Air in flue gases	do	9.6	29.2
Carbon monoxide produced	cubic feet per hour	28.6	.00
Type of flame		(2)	(3)

[1] Analysis made with Orsat apparatus.
[2] Large and very soft.
[3] Medium, hard, no floating or lifting.

A surprising fact concerning this case is the large amount of carbon monoxide (28.6 cubic feet per hour) that was being produced without causing a fatality. The raw gas itself contained 20.6 per cent of carbon monoxide. If the raw gas had escaped without burning, only 19.9 cubic feet of carbon monoxide would have been liberated, which shows that the position of the lower baffle, the dirt on

the burner, and the adjustment of the burner caused the production of an additional 8.7 cubic feet of carbon monoxide.

The heater was fitted with a smaller orifice, the burner was cleaned, the baffle was raised to its proper position (about four coils from the bottom), and the air shutter was set for the proper kind of flame.

This home is located in one of the elevated districts of Baltimore, which causes a higher pressure than the average. The prevailing pressure at this home is about 5 inches. However, when the final adjustment was made the pressure was 6.4 inches, which is slightly above the maximum that it is aimed to maintain. It is of interest to know that if the pressure is 5 inches, the heater as adjusted will still be supplied with 44.2 cubic feet (22,100 B. t. u.) per hour; if 4 inches, 39.5 cubic feet (19,750 B. t. u.) per hour; if 3 inches, 34.2 cubic feet (17,100 B. t. u.) per hour. About 45 cubic feet (22,500 B. t. u.) per hour is the average rated capacity of such water heaters. It will be observed that this heater as adjusted should give satisfactory service even though the pressure should go as low as 3 inches (17,100 B. t. u. per hour) and that it did not produce a trace of carbon monoxide with a consumption of 24,200 B. t. u. per hour at a pressure of 6.4 inches, which was observed at the time the final adjustment was made.

It is believed that some one desired to increase the hot-water capacity of the heater and in order to do so inserted too large an orifice. If this were not true, it would be expected that others in this locality would have a somewhat similar experience. During the entire investigation there were no other cases of poisoning near this section of the city.

Case 14. ILLNESS OF TWO PEOPLE CAUSED BY AN IMPROPERLY DESIGNED WATER HEATER

For about five hours the kitchen of a home had been heated by operating the burners of the oven of a gas range. Two people were in the room during this time and felt no ill effects. The water heater was then operated about one-half hour, at the end of which period the occupants suddenly became very weak, nauseated, and suffered with severe headache. There was no odor from either appliance. The entire water heater was very clean and the adjustment of the burner (rate of consumption and type of flame) was excellent.

Analyses of the room atmosphere made at two and one-half and five hour periods during the operation of the oven showed that only traces of carbon monoxide were produced. The oxygen was not seriously depleted. It was, respectively, 98.1 and 96.2 per cent of normal. Without ventilating the room the water heater was operated one-half hour in addition to the oven. The carbon monoxide amounted to 0.24 per cent of the room atmosphere and the person who took the sample suddenly became ill and walked outside the

room. He immediately collapsed and was unconscious for a short time. A sample of the flue gases issuing from the heater was taken before the room atmosphere had changed. The analysis was as follows:

	Per cent
CO_2	11.5
O_2	.0
CO	6.05
N_2	82.4

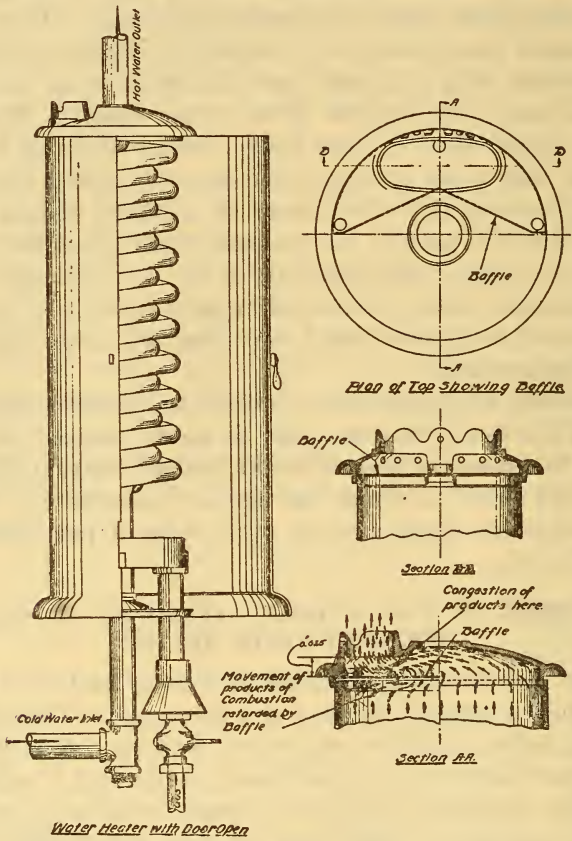


Fig. 11.—*Water heater with dangerously constricted vent*

Further Tests of Water Heater.—At the top of the heater and just below the vent was a baffle which it was believed greatly retarded the escape of the products of combustion and consequently limited the amount of gas that could be burned. It was decided to study the performance of the heater at different pressures with and without the baffle.

Drawings of the heater are shown in Figure 11. The plan and sectional views show the location of the baffle.

The heater was moved to the laboratory to make further tests, and was operated without changing the adjustment of the burner. The results of analyses of samples of flue gases are given in Table 9. Note the small amount of oxygen in the flue gases and its decrease when the rate of consumption was increased.

TABLE 9.—*Tests of water heater with baffle*

Gas pressure in inches	Rate of consumption		Analyses of flue gases				CO produced per hour	Air in flue gases
	Cubic feet per hour	B. t. u. per hour	CO_2	O_2	CO	N_2		
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Cu. ft.*	*Per cent*
2	40.1	20,050	10.0	5.2	0.0	84.8	0.0	24.9
3	49.7	24,850	12.2	2.0	.125	85.6	.25	9.6
3.5	53.0	26,500	12.6	1.1	.628	83.6	1.26	5.3
4	57.7	28,850	12.7	.3	2.20	84.8	4.29	1.4

Usually when so much carbon monoxide is formed by a water heater the blue inner cones lift, the flame floats, and there is a pronounced odor. These things were not observed with this heater during any of the above tests. The burner was adjusted for a harder flame than is usual for water heaters. The conclusion can be drawn from the tests in Table 9 that this heater under the most ideal condition of operation, when the baffle was in use and no other appliance had been burning in the room could not consume more than about 45 cubic feet (22,500 B. t. u.) per hour without causing the formation of an appreciable amount of carbon monoxide.

The heater was again tested without readjustment except for the removal of the baffle. At the highest pressure (3.9 inches) and the highest gas rate (56 cubic feet per hour) available in the laboratory, only 0.01 per cent of carbon monoxide appeared in the products of combustion, which now contained 4.1 per cent of oxygen.

The tests of this heater show that an improper baffle was the primary factor that caused the poisoning. The flue gases from this heater must not contain less than about 5 per cent of oxygen (24 per cent of air) or the combustion will be incomplete.

Case 15. ILLNESS OF 12 PEOPLE CAUSED BY APPLIANCES OUTSIDE OF THE ROOM

About 12 people, mostly young girls, working in the packing and chocolate-dipping rooms of a candy factory became ill and tests of their blood by the pyrotannic-acid method showed the presence of carbon monoxide. The rooms in question had to be kept cool in order to dip chocolate (62° F. or below) which probably resulted in poor ventilation on days that were warm and calm. The rooms were on the second floor.

This incident occurred the day following the repairing of piping in the cooling system and was the first day the rooms had to be cooled after the winter season. People were affected in each of two communicating rooms between which were two passageways always open. The employees claimed that the atmosphere of both rooms on this day was "close and stuffy."

It was about 3 p. m. when several of the employees had become so ill that it was realized something out of the ordinary was wrong. The weather was fairly warm, making it necessary to keep the room closed at all times and to use the cooling system. There had been rain and a heavy mist all day. The wind was very mild. In addition, no gas had been consumed in these two rooms at any time during the day, nor could any odor from leaking gas be detected. It was evident that the carbon monoxide was produced by some appliance or appliances outside of the room. Of the various possibilities all were eliminated except two.

(*a*) Probable Sources of Carbon Monoxide.—It is believed that there are two major sources from which the carbon monoxide may have emanated. In the hallway leading to the rooms in question were two water heaters, one of which was dirty and very poorly adjusted. These two heaters had been operated continuously until the incident occurred. Various employees stated that an odor was detected in the hallway during the day, even though the window was lowered about 8 inches from the top. This window was kept lowered at all times.

On the first floor of the building were two gas-fired boilers of 7 and 10 horsepower. The 10-horsepower boiler had been operated during the day. It consumed about 900 cubic feet of gas per hour. The vent from the boiler was rusted through in places which interfered with proper draft; also, the vent ended just above the top of the roof of the boiler room at about the same level as the base of the windows in the rooms in question. The burners of the gas boiler were very dirty and in need of adjustment. The typical odor which accompanies certain conditions of improper combustion could be detected emanating from the boiler room and vent at the top of the roof and at the windows of the room in question, as well as in the courtyard below.

In Figure 12 is shown a perspective sketch of that portion of the building involved, together with two plan drawings with arrows and notations, clearly indicating the probable movement of the fumes from the gas-fired boiler, as well as from the two water heaters in the hallway. It will be noted that the direction of the mild wind was favorable to cause the fumes from the boiler to permeate the building by entering the loosely fitted windows, also the direction of

the wind prevented the products of combustion from the water heaters from escaping from the top of the window, which had been lowered for that purpose. Thus, when anyone entered the rooms in question, the slight wind caused the fumes from the water heaters, as well as any that may have come from the gas-fired boiler to enter the rooms.

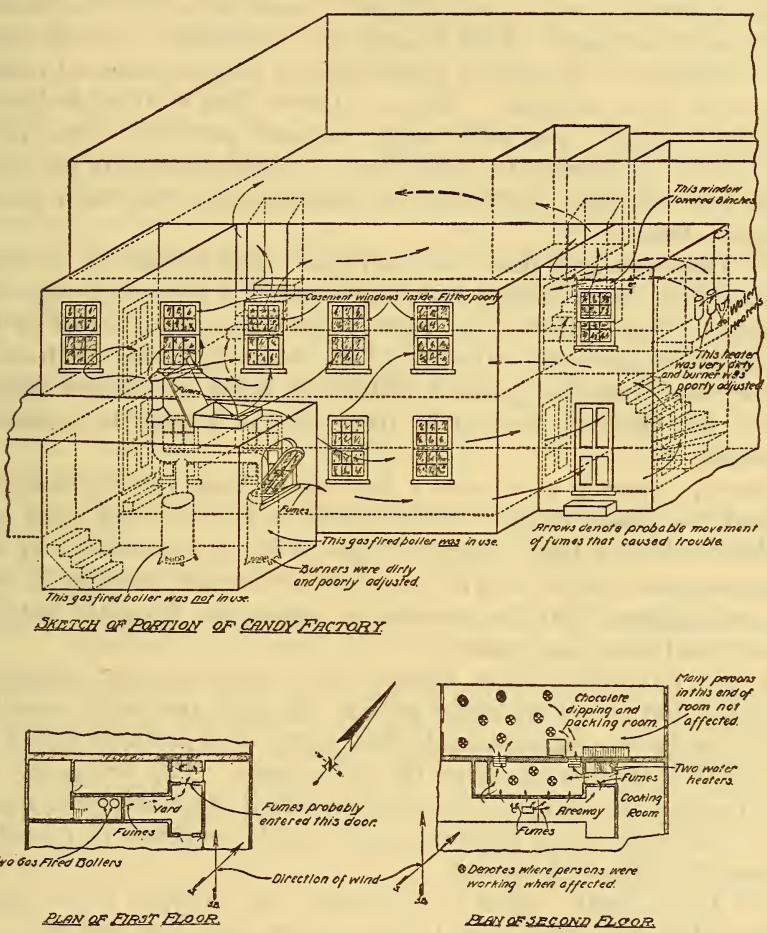


Fig. 12.—*Sketch of candy factory showing probable sources of carbon monoxide*

(*b*) Test of Water Heaters.—Because of the condition of the gas-fired boiler, no test for the total production of carbon monoxide was possible. One of the water heaters in the hallway, which was consuming approximately 45 cubic feet of gas per hour, produced carbon monoxide at the rate of about 1.54 cubic feet per hour. The other water heater, which was consuming approximately 35 cubic feet of gas per hour and was fairly well adjusted, was producing for

that rate of consumption 0.19 cubic foot of carbon monoxide per hour. This makes a total of approximately 1.73 cubic feet of carbon monoxide per hour being produced in the hallway.

The two water heaters were each cleaned, and the burners were adjusted to consume about 40 cubic feet of gas per hour. In order to avoid flash-back troubles the poorly designed burners were not adjusted for the proper type of flame, because the ports of the burners were much too large. After making the readjustment, the products of combustion of the heater producing the larger amount of carbon monoxide were sampled. The test showed that 0.20 cubic foot of carbon monoxide was still being produced per hour. The other heater still produced 0.06 cubic foot of carbon monoxide per hour. This was the best that could be accomplished with such poorly designed heaters.

(*c*) Changes and Recommendations.—The burners of the gas-fired boilers were cleaned and readjusted. A new vent pipe was installed. The outlet of the vent projecting above the roof of the boiler house has been extended 8 feet, resulting in the products of combustion from the gas-fired boiler now being discharged slightly above the level of the roof of the rooms in which the poisoning occurred.

Merely lowering a window a few inches from the top does not permit the proper change of atmosphere in such a small room as a hallway where a large amount of gas is being consumed. It was recommended that so long as the water heaters are operated in such a small hallway that the window be raised also from the bottom, unless the heaters are vented.

A few days after these changes were made another inspection revealed that one of the water heaters was again producing considerable odor because some unauthorized person had partially closed the air shutter, thereby changing the adjustment. This brings out the fact that it is impossible to prevent an unskilled person from changing the adjustment of an appliance from a safe condition of operation to one that creates a hazard.

(*d*) Conclusion.—It is believed that the direction of the wind, which blew the fumes from the boiler into the room, and the poor ventilation, which prevented the escape of carbon monoxide from the water heaters, were the major factors contributing to the poisoning. Since those affected were located in that part of the building nearest the appliances herein described, it is believed that other dirty and poorly adjusted appliances contributed very little to the trouble.

Case 16. FATAL ASPHYXIATION BY ESCAPING GAS WHEN APPLIANCE WAS PULLED LOOSE FROM DETERIORATED RUBBER TUBING

A man known to have been intoxicated was found dead in the kitchen of a home where the gas was flowing from the end of a rubber tubing that had been connected to a three-burner hot plate. It is believed that the victim, who was last seen sitting on a chair near the gas stove, on attempting to arise probably staggered and grasped the stove and pulled it from the shelf. The stove was found in the position shown in Figure 13.

The rubber tubing was so deteriorated that it partially broke about midway from the connections. The gas had evidently been leaking at the connection of the tubing to the house piping because a rag was wrapped around the joint and was tied on with string. Another glaring mistake in the installation was the absence of a gas cock in the gas line in the kitchen. In order to stop the flow of gas it was necessary to go to the basement and close the valve near the meter. The housewife, when asked why there was no valve in the gas line in the kitchen by which to turn off the gas so the tubing would not always be under gas pressure, and why such old tubing tied on with a rag to stop leaks was being used, replied, "It is the first time this thing has happened in four years."

This case further illustrates the carelessness and ignorance of some people. It requires a serious accident to impress upon them the necessity of proper equipment and installation.

Case 17. ILLNESS OF SEVEN PEOPLE CAUSED BY IMPROPER COMBUSTION IN THREE UNVENTED PRESSING MACHINES

Seven people working near three gas-fired boilers of pressing machines were poisoned from carbon monoxide in the products of combustion that were allowed to escape into the room. The room had 11 windows and was 96 feet long by 20 feet wide. The end of the room where the poisoning occurred was semisubdivided and was 23 by 20 feet by 9 feet 6 inches (volume = 4,370 cubic feet).

The trouble was provoked when one of the workers partially closed the air shutter of the burners of two of the boilers. This reduced the injection of primary air, and caused a large soft flame that could not be completely aerated at the rate gas was burned. About 60 cubic feet of gas per hour (30,000 B. t. u.) was being burned under each boiler.

The field work of the investigation had been concluded when this case occurred and a detailed study was not made. To offset the possibility of recurrence of poisoning, in case an improper adjustment of burners should again be made, the machines were connected to flue pipes. It is always advisable to connect appliances which burn so much gas to flues.

Case 18. CARBON MONOXIDE FROM A COAL-FIRED FURNACE

The publicity concerning this investigation resulted in the medical profession detecting the source of some perplexing causes of illness. A doctor who was unable to locate any internal ailment of a patient requested that a test of the blood be made to determine whether carbon monoxide might be the cause. The tannic-acid method of test of the blood showed that carbon monoxide was in the blood of the patient.

The invalid was in a bedroom on the second floor of a six-room house. It was found that a check draft of the pipeless furnace in the basement was open and that when the damper was closed the products of combustion came out through the check draft and the feed door as well. The flue pipe, which was 6 inches in diameter

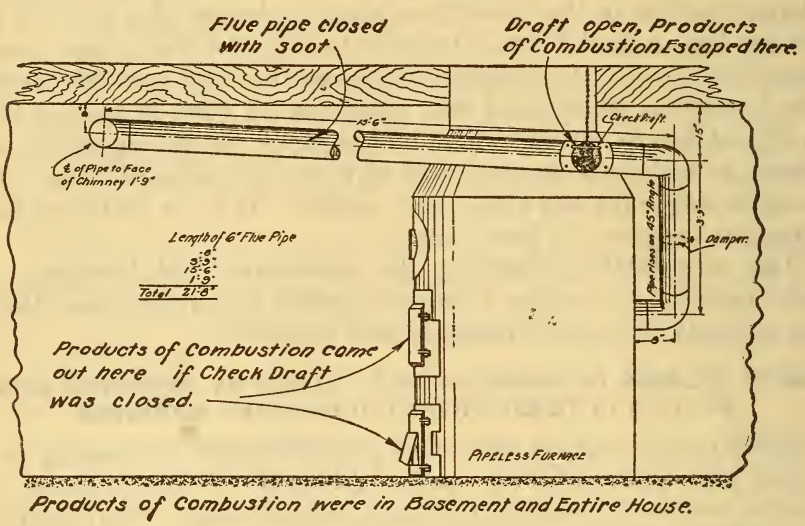


Fig. 14.—*A dangerous installation of a coal furnace with adequate flue*

and about 22 feet long, as shown by Figure 14, was obstructed by soot, although it had been cleaned less than two months previously. During three weeks of this period soft coal was burned.

The window of the sick room was lowered about 3 inches from the top at all times. It was evident from the odor in the home that the products of combustion from the furnace had penetrated every room in the house.

The air in the house was sampled in three places. That taken near the furnace and 5 feet from the floor contained 0.454 per cent of carbon monoxide. In the front room on the first floor there was 0.043 per cent of carbon monoxide and in the hallway of the second floor, 0.042 per cent of carbon monoxide. These tests showed that (1) the basement atmosphere near the furnace was very dangerous

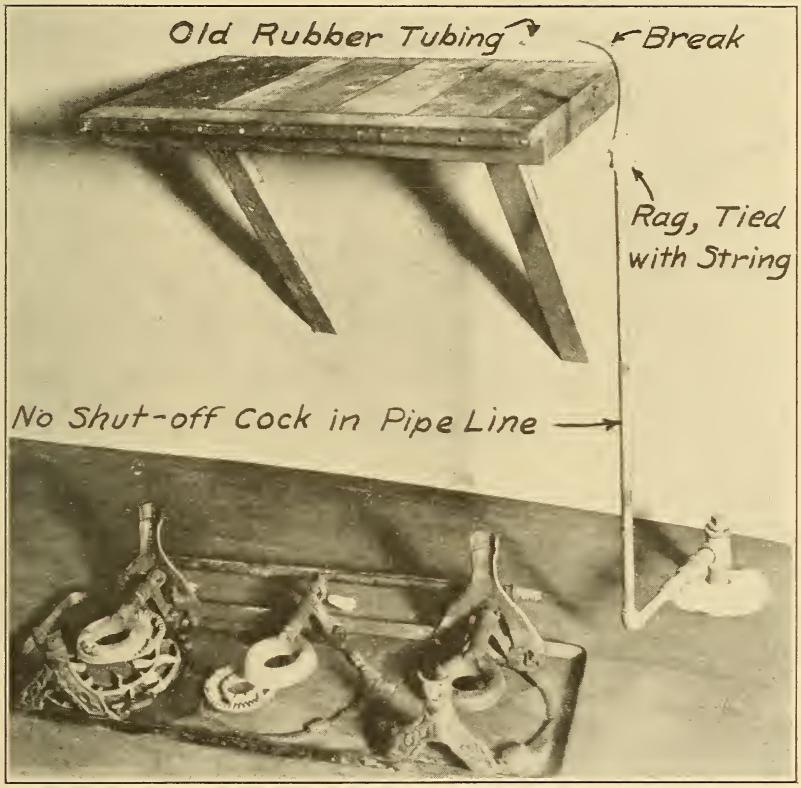


Fig. 13.—*An improperly connected hot plate after a fatal accident*

to health, and it was fortunate that no one lingered long when in the basement; (2) the atmosphere of the first and second floors was such as to cause the ailment of the person in question.

The building inspector's office of Baltimore joined in the inspection of the installation of the pipeless furnace, and it was agreed that the flue pipe was decidedly too small, too long, and contained too many right-angle bends. The draft was probably not good even when the flue pipe was clean.

Case 19. DANGER FROM EXHAUST GAS OF AUTOMOBILE

One person was overcome and another was made ill while working in the repair shop of a garage in which a six-cylinder automobile had been running at idling speed for about one and one-half hours. The weather was cold and all windows were closed, as well as the large double door between the shop and the garage proper. There were six windows in the room in question. The room had a volume of about 21,000 cubic feet.

Test of Shop Atmosphere.—The automobile was operated for one and one-half hours, after which a sample of the atmosphere was taken about 5 feet from the floor and at the approximate location in the room where the two persons were working at the time of the accident. The analysis showed 0.09 per cent of carbon monoxide. These men were engaged in locating a knock in the engine and were in and around the machine most of the time.

IV. STRATIFICATION OF PRODUCTS OF COMBUSTION IN AN UNVENTILATED ROOM

A number of times during the investigation the question was asked, "Do the products of combustion diffuse evenly throughout a closed room?" Various individuals wondered whether carbon monoxide and carbon dioxide would settle to the floor or form strata at the ceiling. If either happened, it would be of great interest in connection with studying cases of carbon monoxide poisoning and would have an important bearing on the ventilation of rooms in which the products of combustion from appliances are liberated.

A radiant heater of five-radiant size which was known to produce carbon monoxide was selected for the study of diffusion of the products of combustion. The tests were made in the unventilated chamber. Samples were drawn from the middle of the room at the level of the floor, 5 feet above the floor, and at the ceiling, 9 feet 4 inches above the floor. The heater was placed about 5 feet from the center of the chamber in line with a corner. The agitator fan was not operated and no one entered the chamber while the tests were in progress.

56597°—26†——4

The operation of the heater was continued for four and eight-tenths hours and samples of the atmospheres were analyzed from the three levels at intervals. As we should expect from the tendency of the hot gases to rise, there was a slight concentration of products of combustion near the ceiling, but the difference in the composition of the atmosphere at the different levels was not great enough to have practical significance.

In Table 10 are given the quantities of gas consumed, the carbon monoxide, carbon dioxide, and oxygen concentrations of the chamber

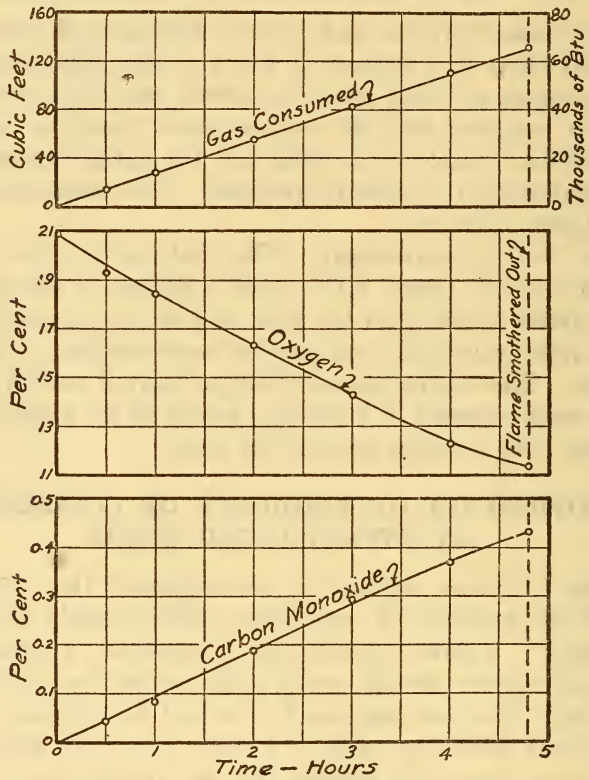


FIG. 15.—*Volume of gas consumed and percentages of oxygen and carbon monoxide in atmosphere of unventilated chamber during operation of a five-radiant room heater*

at three elevations at stated intervals. The samples were simultaneously drawn from the chamber.

The radiant heater was operated until the flame was extinguished. When the flame ceased to burn the atmosphere contained about 11.5 per cent of oxygen (55 per cent of normal), about 5.8 per cent of carbon dioxide, and 0.43 per cent of carbon monoxide. The gas consumed and the values of oxygen and carbon monoxide obtained

in the samples taken 5 feet from the floor are plotted in Figure 15. The rate of consumption of gas was constant. The curve of Figure 15 shows that this particular radiant heater produced carbon monoxide at practically a constant rate until the flame was extinguished from deficiency of oxygen. Tests of the effect of deficiency of oxygen on the performance of other types of appliances when operated in the unventilated chamber are reported in a following section:

TABLE 10.—*Analyses of atmosphere at different elevations in unventilated chamber during operation of a five-radiant heater*

[Volume of chamber=1,120 cubic feet]

Time in hours	Total gas consumed		Chamber temperature [1]	Analyses of chamber atmosphere								
				CO			CO_2			O_2		
	Cubic feet	B. t. u.		Floor	5 feet high	Ceiling (9 feet 4 inches)	Floor	5 feet high	Ceiling (9 feet 4 inches)	Floor	5 feet high	Ceiling (9 feet 4 inches)
			°F.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0	0	0	66	0	0	0	0	0	0	20.9	20.9	20.9
0.5	14.1	7,050	77	0.039	0.043	0.045	0.7	1.1	1.3	19.5	19.3	19.3
1	27.8	13,900	80	.076	.085	.091	1.2	2.1	1.6	19.3	18.4	18.1
2	55.1	27,550	88	.169	.189	.203	3.0	3.1	3.1	16.5	16.3	16.2
3	82.8	41,400	----------	.280	.293	.302	4.2	4.4	4.6	14.5	14.3	14.5
4	110.1	55,050	97	.368	.370	.377	5.4	5.6	5.8	12.6	12.3	12.3
4.8 [2]	131.5	65,750	100	.420	.428	.441	5.6	5.8	6.0	11.7	11.4	10.2

[1] Chamber temperature was taken near observation window about 5 feet from floor.
[2] Flame went out; smothered from deficiency of oxygen.

NOTE.—Flame streamed from top of radiants. Rate of consumption per radiant was excessive. Gas consumed per radiant per hour=2,780 B. t. u.

V. EFFECT OF DIMINISHED OXYGEN CONTENT OF ATMOSPHERE ON PERFORMANCE OF APPLIANCES

It is the practice of some people during the winter months to ignore proper ventilation of living rooms, bedrooms, and kitchens. Asphyxiations caused by such carelessness are occasionally reported in the press. Fatalities sometimes occur when people go to bed in closed bedrooms while a heater is burning. In such cases it is frequently found that the heater is improperly designed and produces carbon monoxide even when operated in a normal atmosphere.

There are many types and numerous designs of appliances that are being used in atmospheres containing appreciably less than the normal amount of oxygen. No data showing the effect of depletion of oxygen on the performance of appliances burning manufactured gas have been published. The Bureau of Mines [12] has obtained valuable and useful information from such tests conducted with natural gas.

[12] Bureau of Mines Tech. Paper No. 337, Carbon Monoxide Hazards From House Heaters Burning Natural Gas, by G. W. Jones, L. B. Berger, and W. F. Holbrook.

These tests will suffice to show that some appliances will completely burn the gas even though the oxygen content of the atmosphere is reduced much below that which is likely to occur in rooms with unusually restricted ventilation.

It will be apparent to the reader that the performance of an appliance is dependent on the manner in which air is supplied to the region of the flame. The greater the inclosure of the flame or baffling which restricts either the access of air to the flame or the escape of the burned gases, the less adaptable to varied conditions will be the appliance. The tests show that appliances with well-aerated flames can be safely operated in an atmosphere of surprisingly low oxygen content.

Because of lack of time, it was decided to study the performance of appliances at only one gas pressure in the unventilated chamber tests. All of the appliances in the following tests were operated with a gas pressure of 3.5 inches.

1. UNVENTILATED CHAMBER TEST OF THE PERFORMANCE OF A "YELLOW-FLAME" ROOM HEATER

The heater used to make this study was selected because the opinion had been expressed that it might not be designed to properly burn the gas. If so, it might have been the cause of the ill health of an elderly person who attempted to commit suicide. The person lived mostly in a room that was heated by this appliance. It was of interest to know whether this heater burned the gas completely when the ventilation was so poor that the oxygen content of the atmosphere was appreciably reduced.

A photograph of the heater is shown in Figure 16. The door at the front is open and the refractory tips of the burner are plainly seen. The heater was in excellent condition when removed from the home. The tips were not clogged. The flame spread readily from tip to tip.

The quantities of gas consumed and of oxygen and carbon monoxide in the atmosphere at various intervals until the flame of the heater was completely smothered are shown in Figure 17. The agitator fan was operated throughout the entire time of the test so that the products of combustion were at all times evenly distributed in the chamber atmosphere. A pungent odor was noticeable after two hours, and caused severe smarting of the eyes in five hours. The yellow color of the flame was seen to be disappearing at the end of four hours, and at the end of five hours the flame was entirely blue. The temperature within the chamber increased from 72 to 100° F. during the course of the test.

It is of interest to note that when the flame ceased to burn the chamber atmosphere contained 11.9 per cent of oxygen (57 per cent

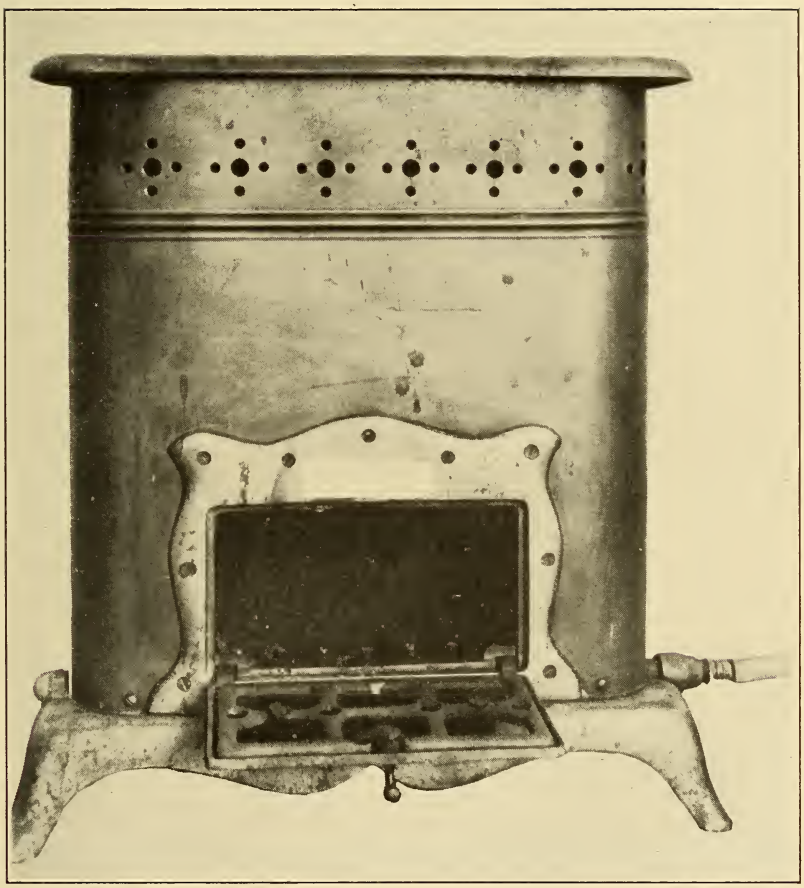


Fig. 16.—*The "yellow flame" heater tested in the unventilated room*

of normal), 5.9 per cent of carbon dioxide, and only 0.079 per cent (0.88 cubic foot) of carbon monoxide. It is believed that the reason such a small quantity of carbon monoxide was produced by this heater in comparison with some other types of appliances was the absence of baffling devices. The burned gases could escape freely and there was free access of air to the flame.

Throughout the time the test of this heater was being conducted two guinea pigs were in the chamber. Although they were still alive when the flame was extinguished from deficiency of oxygen, they were entirely helpless. The condition of the pigs and the fact

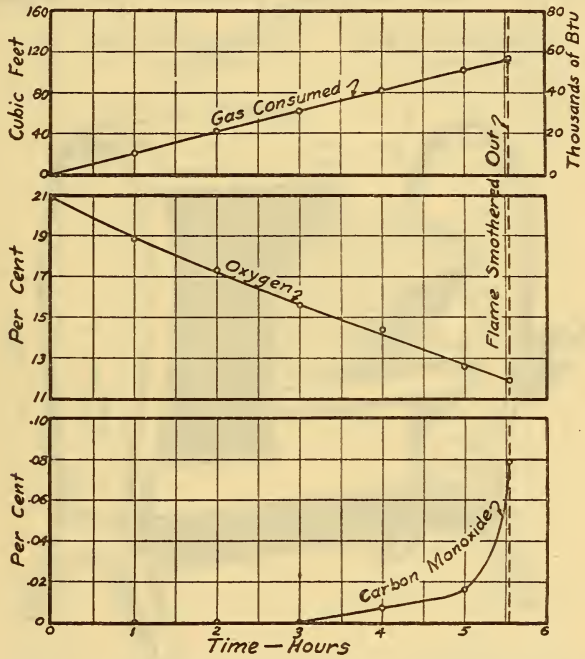


FIG. 17.—*Gas consumed and changes in the atmosphere of the unventilated chamber during the operation of the yellow-flame heater*

that they were active until about an hour before the end of the test was additional proof that carbon monoxide was not being produced at a high rate. The excessive temperature and the greatly diminished oxygen content of the chamber atmosphere may have contributed to the condition of the pigs.

It is sometimes stated that a yellow flame produces carbon monoxide, even though the atmosphere is normal and the supply of air and exit of burned gases are not hampered. The study of this heater and the tests of a yellow-flame heater (of another design), which are reported in another section of this paper, have shown the opposite to be true.

The public has formed the general impression that the yellow-flame type of heater is both unsafe and very inefficient. It is erroneously believed by some that carbon monoxide is formed only by a yellow flame. When the combustion is complete the same number of heat units are liberated from burning the same volume of gas of a given heating value irrespective of the type of the appliance.

2. UNVENTILATED CHAMBER TEST OF THE PERFORMANCE OF A "BLUE-FLAME" ROOM HEATER

The heater used in this study was removed from a home where it was believed an invalid had been poisoned from improper com-

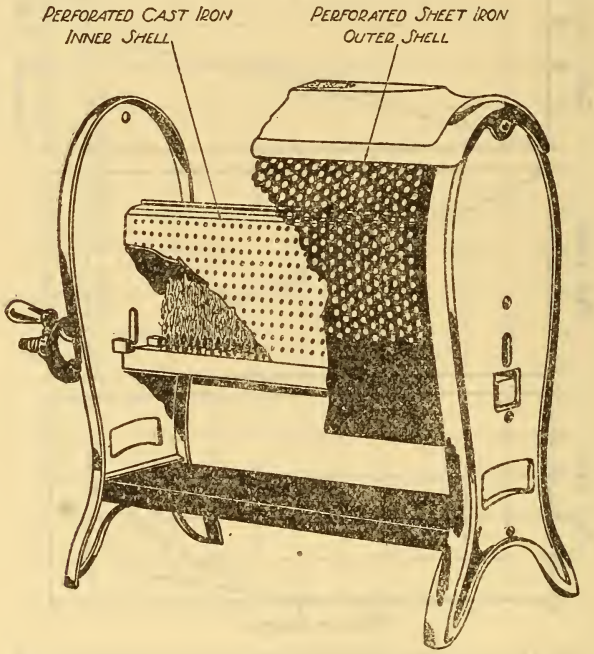


Fig. 18.—*The "blue flame heater" tested in the unventilated chamber*

bustion of the gas. Another person who had continually occupied the room with the patient was apparently not affected, but this is not proof that carbon monoxide was not present. The heater had been operated about six hours in a room of 1,150 cubic feet capacity, which had two windows. One window was lowered not more than 6 inches, but the blind, which fitted closely, was also lowered about three-fourths the distance. There was some question of the effectiveness of the provision for ventilation.

The heater was clean and was connected to the gas supply by a flexible metal-covered tube that was gas tight. The burner was adjusted for the proper type of flame. The first person to arrive on

the scene did not detect any unusual odor in the room or any gas leaks. An investigation revealed that the appliances in adjoining rooms were not in operation. In Figure 18 is shown a sketch of the type of the heater that was in use. An analysis of the gases containing products of combustion sampled about 1 inch above the opening at the top of the heater showed that it did not produce carbon monoxide under normal operation.

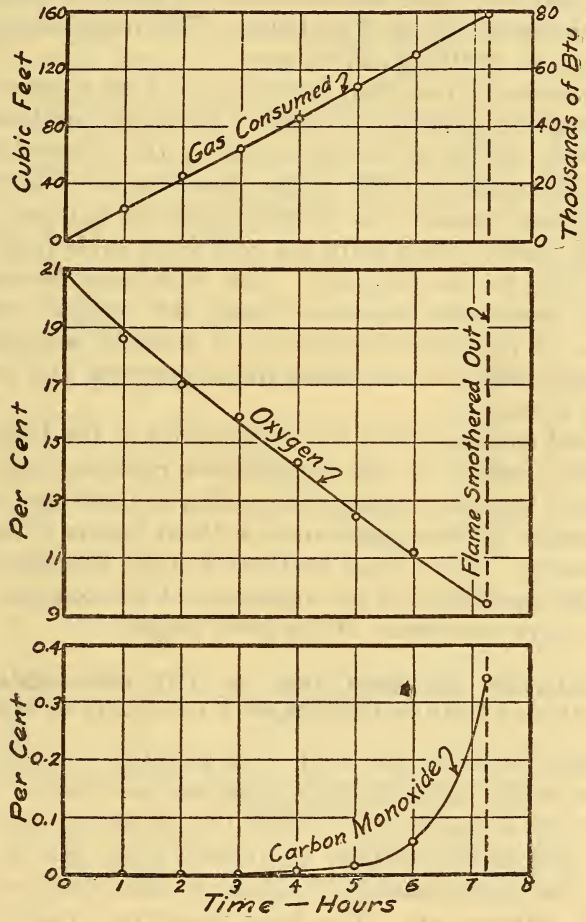


FIG. 19.—*Gas consumed and changes in the atmosphere of the unventilated chamber during the operation of the blue flame heater shown in Figure 18*

The heater was operated in the unventilated chamber until the flame was extinguished from diminution of oxygen. The percentages of oxygen and carbon monoxide and the quantity of gas consumed are plotted in Figure 19 and clearly show how smothering of the flame affected the performance of the heater. It will be observed that

after the heater had been in operation three hours the oxygen content of the chamber was 15.9 per cent (76.1 per cent of normal) and only a trace of carbon monoxide was present. Furthermore, the chamber atmosphere contained only 0.014 per cent (0.16 cubic foot) of carbon monoxide when the oxygen content was reduced to 12.4 per cent (59.3 per cent of normal). The blue inner cones of the flame disappeared after 5 hours. The flame elongated until it streamed from the top of the heater at the end of 6 hours. It was entirely smothered out in 7.25 hours. The room temperature increased from 66 to 105° F. in 6 hours.

It is of interest to note that on the basis of the oxygen content of the chamber the quantity of carbon monoxide produced by this heater is very similar to that produced by the yellow-flame heater.

During the operation of the yellow-flame heater when the oxygen content of the chamber had been reduced to 12.6 per cent (60.3 per cent of normal), only 0.016 per cent (0.18 cubic foot) of carbon monoxide was in the chamber. The blue-flame heater was not completely smothered, however, until the oxygen content was reduced to 9.4 per cent (45 per cent of normal), while the yellow-flame heater ceased to burn when the oxygen was 11.9 per cent (57 per cent of normal).

One would conclude from the performance of the blue-flame and yellow-flame heaters in the unventilated chamber that either of these types of heaters, if constructed similar to those used in the tests, can be operated in the average room without danger of carbon monoxide poisoning. The normal ventilation of the average room would preclude the possibility of the reduction of the oxygen content to the point where smotherin of the flame begins.

3. UNVENTILATED CHAMBER TEST OF THE PERFORMANCE OF A RADIANT ROOM HEATER OF FOUR-RADIANT SIZE

The heater used in this study was selected at random from a stock room supply and, therefore, was new and clean. The heater was built with a fixed orifice. When the air shutter was wide open the flame was of the medium or average type; that is, the flame character was approximately the same as that used with top and oven range burners, etc. The flame would not readily flash back and burn within the mixing tube, though the burner has ports of a size through which a very hard flame will pass. Therefore, the heater was operated with the air shutter wide open.

It was known that this four-radiant heater produced a small amount of carbon monoxide, even when operated in a normal atmosphere. A sample of the gases containing products of combustion obtained along the front and near the top of the heater after it had been burning one hour in a well-ventilated room contained:

	Per cent
CO_2	2.0
O_2	17.5
N_2	80.4
CO	.043

Gas pressure=3.5 inches.
Carbon monoxide produced per hour=0.16 cubic foot.
Gas consumed per hour=16.8 cubic feet (8,400 B. t. u.).

The results of analyses of the unventilated chamber atmosphere during the operation of this heater until the flame was extinguished from deficiency of oxygen are shown in Figure 20.

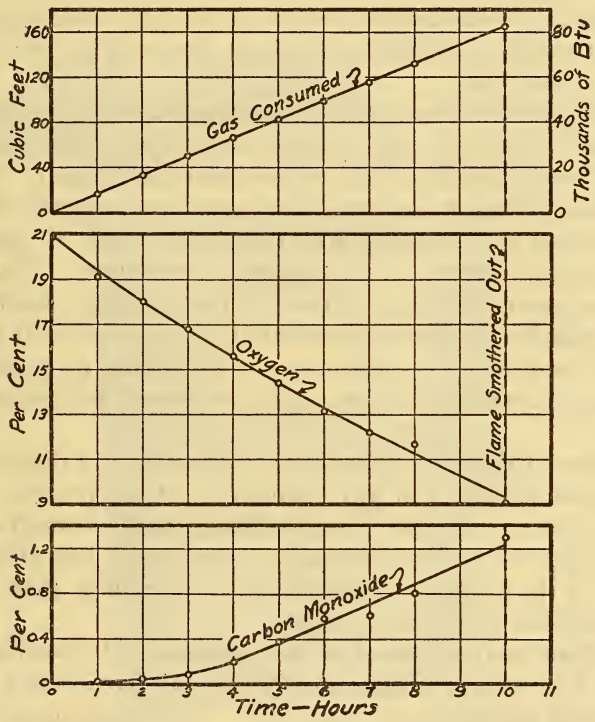


FIG. 20.—*Gas consumed and changes in the atmosphere of the unventilated chamber during the operation of the four-radiant room heater*

The slope of the curves show that the rate of consumption of gas was constant and that the rate of utilization of oxygen decreased as the rate of formation of carbon monoxide increased. When the flame ceased to burn the chamber atmosphere contained about 9 per cent (43 per cent of normal) oxygen and about 14.6 cubic feet (1.3 per cent) of carbon monoxide. The determinations for carbon monoxide at 7, 8, and 10 hours were made with the Orsat apparatus.

It is interesting to compare the test of this heater with the corresponding test of the five-radiant heater used in the study of stratification of the products of combustion. The five-radiant heater ceased to burn when the oxygen content of the chamber was about 11.5 per cent (55 per cent of normal) and there had been produced in the chamber about 4.8 cubic feet (0.43 per cent) of carbon monoxide. Under normal operating conditions the five-radiant heater was producing about 0.7 cubic foot of carbon monoxide from the combustion of 20 cubic feet of gas, while the four-radiant heater formed only about 0.15 cubic foot during the combustion of the same volume of gas. When about 11.5 per cent oxygen remained in the chamber in each case, the four-radiant heater had formed about 9 cubic feet of carbon monoxide and the five-radiant heater had produced only about 4.8 cubic feet.

In a normal atmosphere the flame streamed considerably from the top of the radiants of the five-radiant heater. The rate of consumption was about 2,750 B. t. u. per hour per radiant. There was no streaming of the flame from the top of the radiants of the four-radiant heater in a normal atmosphere, the rate of consumption being only about 2,050 B. t. u. per hour per radiant. The curves of the carbon monoxide values of the two heaters show clearly that the rate of formation of carbon monoxide by the five-radiant heater was practically constant as smothering of the flame progressed; while that of the four-radiant heater rapidly increased with smothering of the flame.

It is believed that the radiants were so similar in design that this factor can be neglected in any comparison of the results. When so much gas is being consumed that the flame streams from the radiants, the production of carbon monoxide seems to be less affected by a reduction of the oxygen content of the atmosphere than when the flame is confined within the radiant.

The radiant heaters tested in the unventilated chamber were all so designed or adjusted that they would produce carbon monoxide under normal conditions of operation. Their performance is not to be interpreted as necessarily typical of all radiant heaters, many of which burn the gas completely.

4. UNVENTILATED CHAMBER TEST OF THE PERFORMANCE OF FOUR STAR-SHAPED COOKING TOP BURNERS OF GRATE-TOP GAS RANGE SHOWN IN FIGURE 21

There are many kitchens that are generally considered to be poorly ventilated. Some kitchens are quite small and only a relatively short time is required to greatly diminish the oxygen content of the atmosphere when a number of burners are in operation unless

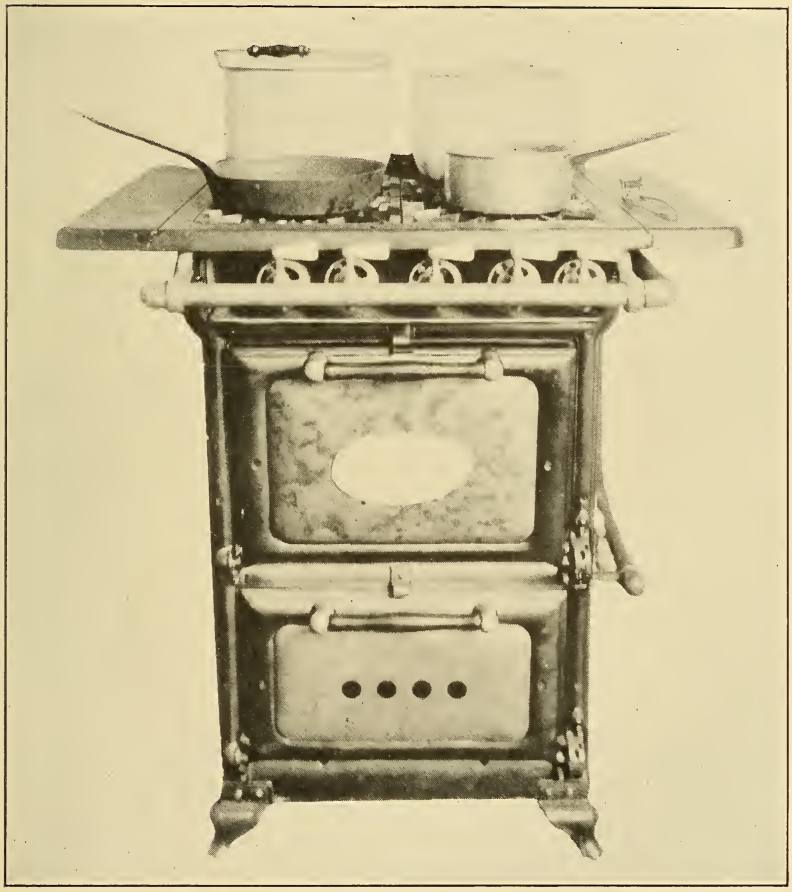


FIG. 21.—*First range used in "unventilated chamber" tests*

unusual provision is made for ventilation. It was considered essential as part of the investigation to study the performance, in the unventilated chamber, of the cooking top and oven of several of the types of ranges most widely used in Baltimore.

The first range studied (which will be designated range No. 1) had a grate cooking top. It will be observed from Figure 21 that three of the utensils which were placed above the top burners are of large diameter. The larger the diameter of the utensil the greater the retarding of the escape of the burned gases and the greater the possibility of improper aeration of the flame. This test may be considered as rather rigid.

The burners were adjusted for the proper type of flame and the proper consumption of gas. Three of the burners were of regular "4-inch" or standard size and one burner was of "5-inch" or giant size. The range was constructed so that the burners were 1⅜ inches below the bottom of the utensils, which is about the average distance for ranges used to burn manufactured gas.

The results of the unventilated chamber tests of the four top burners are given in Table 11. At the end of one-half hour the chamber atmosphere contained 0.016 per cent (0.18 cubic foot) of carbon monoxide, the oxygen content was 17.1 per cent (81.8 per cent of normal) and the temperature in the chamber was 110° F. The rate of consumption of gas by four burners of the cooking top when fully turned on causes a very rapid increase of the temperature of the average room, if there is lack of proper ventilation. It necessitates provision for adequate ventilation to make the room comfortable. Except possibly in cold weather it is believed that the danger of poisoning from such well designed grate cooking tops is very remote because an excessive room temperature would occur before the oxygen content is seriously depleted.

TABLE 11.—*Analyses of atmosphere of unventilated chamber during operation of four star-shaped cooking top burners of grate-top gas range in Figure 21 with a utensil above each burner.*

[Ports of burners below base of utensils, 1⅜ inches. Volume of chamber=1,120 cubic feet]

Time in hours	Total gas consumed		Chamber temperature	Analyses of chamber atmosphere				Carbon monoxide in chamber	Oxygen in chamber (per cent of normal)
	Cubic feet	B. t. u.		CO_2	O_2	N_2	CO		
			° *F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Cubic feet*	
0	0	0	78	----------	20.9	79.1	----------	----------	100.0
¼	22.1	11,050	101	1.1	18.5	80.4	0.000	0.00	88.5
½	41.9	20,950	110	2.2	17.1	80.6	.016	.18	81.8
¾	61.6	30,800	116	3.3	15.3	81.3	.057	.64	73.2
1	79.4	39,700	120	4.0	13.6	82.2	.160	1.79	65.1

5. UNVENTILATED CHAMBER TEST OF THE PERFORMANCE OF OVEN OF GAS RANGE SHOWN IN FIGURE 21

The oven of range No. 1 was located below the cooking top and was designed with two burners. The burners were adjusted for the proper type of flame and an excellent supply of gas (about 24.000 B. t. u. per hour).

In Table 12 are given analyses of the chamber atmosphere at one-half hour intervals during a three-hour test. The performance of this oven is most interesting. When the oxygen concentration of the chamber was 11.7 per cent (56 per cent of normal) the carbon monoxide was only 0.009 per cent (0.10 cubic foot). Evidently the provision for circulation of air in this oven and the aeration of the flame was excellent. The possibility of improper performance from the effect of a diminished oxygen content in the average kitchen appears to be exceedingly remote.

TABLE 12.—*Analyses of atmosphere of unventilated chamber during operation of oven burners of gas range of Figure 21*

[Volume of chamber=1,120 cubic feet]

Time in hours	Total gas consumed		Chamber temperature	Analyses of chamber atmosphere				Carbon monoxide in chamber	Oxygen in chamber (per cent of normal)
	Cubic feet	B. t. u.		CO_2	O_2	N_2	CO		
			° *F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Cubic feet*	
0	0	0	64	----------	20.9	79.1	----------	----------	100.0
0.5	24.7	12,350	----------	1.2	18.9	79.9	0	0	90.5
1	48.1	24,050	92	2.8	17.0	80.2	0	0	81.4
1.5	70.1	35,050	101	4.1	15.1	80.7	(1)	----------	72.3
2	91.8	45,900	106	5.2	13.6	81.1	.005	.06	65.1
2.5	112.6	56,300	112	6.2	11.7	82.0	.009	.10	56.0
3	135.6	67,800	115	7.6	9.9	82.4	.066	.74	47.4

[1] Trace.

6. TESTS OF OTHER APPLIANCES IN UNVENTILATED CHAMBER

Tests similar to the above were made in the unventilated chamber with another gas range (No. 2) having four star-shaped burners, located 1½ inches below the grate top; with the oven of the same range; with the solid cooking top of a range equipped and operated with four burners and designed with a vent which was not connected to a flue; with the same solid cooking top when connected to a 3-inch flue pipe terminating outside the chamber; with the oven having an inverted channel-shaped flame spreader described in case 2. The important results of all the unventilated chamber tests are shown in Table 13.

It should be noted that the vented solid-top stove showed no better combustion than the unvented one as indicated by the relative amounts of carbon dioxide and carbon monoxide liberated and that not more than half the products of combustion left the chamber

through the vent. The ports of the burners were only 1⅛ inches below the undersurface of the solid top. The opening into the vent at the rear of the burner box was 15.4 square inches. An opening in the side of the chamber of 4 square inches for entrance of replacement air was provided during test 9 and during a ventilation test of the oven used in test 10. This ventilation test was made with the oven connected to a flue pipe terminating outside the chamber. Analyses made during an hour showed that the products of combustion were completely removed from the chamber.

TABLE 13.—*Summary of unventilated chamber tests*

Appliance tested	Duration of test	Volume of gas burned	Composition of atmosphere			Oxygen in chamber (per cent of normal)
			CO_2	O_2	CO	
	Hours	*Cubic feet*	*Per cent*	*Per cent*	*Per cent*	
1. Yellow-flame heater	3.0	62.6	3.6	15.6	(1)	74.6
	5.0	102.5	5.4	12.6	0.016	60.3
	[2] 5.55	114.7	5.9	11.9	.079	57.0
2. Blue-flame heater	3.0	64.4	3.4	15.9	(1)	76.1
	6.0	129.5	6.2	11.2	.056	53.6
	[2] 7.25	157.5	7.4	9.4	.340	45.0
3. Radiant heater, 4-radiant size	1.0	16.2	.5	19.1	.011	91.4
	3.0	50.2	2.4	16.8	.082	80.4
	5.0	82.6	3.9	14.4	.371	68.9
	7.0	115.2	4.8	12.2	.6	58.4
	[2] 10.0	165.3	5.5	9.0	1.3	43.1
4. Grate top of range No. 1	.5	41.9	2.2	17.1	.016	81.8
	.75	61.6	3.3	15.3	.057	73.2
	1.0	79.4	4.0	13.6	.160	65.1
5. Oven of grate top range No. 1	1.0	48.1	2.8	17.0	.0	81.4
	2.0	91.8	5.2	13.6	.005	65.1
	3.0	135.6	7.6	9.9	.066	47.4
6. Grate top of range No. 2	.5	36.8	1.6	17.7	.007	84.7
	.75	55.5	2.6	16.4	.010	78.5
	1.0	74.6	3.4	15.2	.029	72.7
7. Oven of grate top range No. 2	.5	20.3	.9	19.0	(1)	90.9
	.75	29.6	1.4	18.3	.005	87.6
	1.0	38.7	1.7	17.9	.006	85.7
8. Solid-top range unvented	.5	36.6	1.7	17.8	.143	85.2
	1.0	67.2	3.2	15.4	.272	73.7
9. Solid-top range vented to outside of chamber	.5	35.7	1.0	18.8	.095	90.0
	1.0	67.6	1.8	17.5	.171	83.8
10. Oven with inverted channel-shaped flame spreader	.5	31.8	1.3	18.0	.004	86.1
	1.0	64.1	3.7	15.3	.049	73.2

[1] Trace. [2] Flame smothered out from deficiency of oxygen.

VI. EFFECT OF CHANGE OF PRESSURE ON PERFORMANCE OF GAS APPLIANCES

Largely because of variations in the demand for gas by consumers it is difficult to maintain a constant pressure of the gas throughout an entire distributing system. Gas appliances must, therefore, be quite adaptable to variations in the rate of consumption and the flame

characteristics of different kinds of gas. Enough secondary air must be available to complete combustion under all conditions, and this must be provided for in the design of the appliance. Most gas appliances are intended to be so designed.

It was considered advisable to make some tests to ascertain if the safe performance of appliances was exceeded when the gas consumption was greatly increased because of an increase of gas pressure. Three such tests were made. An oven of good design which gave satisfactory service with 50 cubic feet of gas per hour (25,000 B. t. u.) was operated with 82.4 cubic feet per hour (41,200 B. t. u.) without a trace of carbon monoxide being produced. The flue gases contained 9.5 per cent of oxygen (45.4 per cent of air). The oven referred to under case 2, which had a flame spreader in the form of an inverted channel, produced at all pressures a nearly uniform small amount of carbon monoxide, 0.22 cubic foot per hour, which is attributed to the diversion from the flame of a certain amount of unburned gas. The flue gases from this oven contained 14.9 per cent of oxygen (71.3 per cent of air) when the rate of consumption was 82.8 cubic feet per hour (41,400 B. t. u.). Tests of a water heater of good design indicated that the formation of carbon monoxide occurs only when the amount of gas used is too great to be burned by the amount of secondary air naturally circulated through the heater.

Some manufacturers of water heaters sell their product through jobbers and do not know when a heater is shipped from the factory whether it will be operated with manufactured or natural gas, nor is the pressure or heating value of the gas known. Consequently, it is the policy of some manufacturers to attach two sizes of orifices. The larger orifice is intended for use with manufactured or mixed gas. The smaller orifice is for natural gas. In order that localities with low-gas pressures or heating values may be adequately served, the orifices sent out are frequently too large for use in other places, and their installation constitutes a serious hazard.

A water heater of a design widely used in Baltimore was operated at pressures of 2, 4, 6, and 7 inches with two sizes of orifice designated by "A" and "B." After the orifice in each case was inserted the air shutter of the burner was adjusted for the proper type of flame. The flue gases were sampled as they issued from the vent. Carbon monoxide was not produced at any of these gas pressures when the heater was equipped with orifice A. With orifice B when the pressure was 6 inches and 68.8 cubic feet per hour was being consumed, carbon monoxide was formed at the rate of 0.19 cubic foot per hour. When the pressure was 7 inches, the rate of consumption of gas was 73.4 cubic feet per hour and 0.43 cubic foot of carbon monoxide was produced per hour.

The values of rate of consumption of gas, the per cent of air in the flue gases, and the equivalent in per cent of oxygen are plotted in Figure 22. It can be deduced from these curves that the amount of gas burned is the factor that affected the limit of safe performance of the water heater. By comparing values taken from the curves it

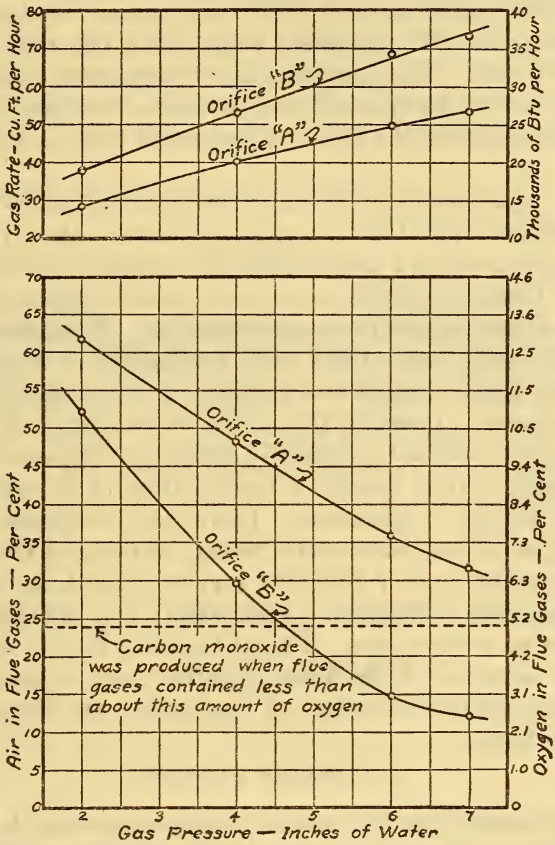


FIG. 22.—*Curves showing the effect of pressure and change of orifice on the amouni of gas burned and the excess air in the flue gases*

will be observed that if the same amount of gas was being burned with orifice A as with orifice B, the flue gases contained approximately the same per cent of air. About 30,000 B. t. u. per hour appears to be the safe limit of operation of this heater when it is clean and properly adjusted. Under this condition of operation the flue gases would contain about 5 per cent of oxygen (24 per cent of air).

VII. SUMMARY AND RECOMMENDATIONS

Asphyxiations from improper combustion of gas were found to be caused by faults in the design of appliances, improper installations, improper adjustments, deterioration or clogging of vital parts, carelessness, ignorance, etc. In attempting to summarize these causes and to offer recommendations which it is hoped will assist in reducing the occurrence of incomplete combustion one must do so with some reservations. The important fact to remember is that improper combustion occurs when a sufficient amount of oxygen does not gain access to the region of the flame at the proper time and in the proper manner.

Usually a number of factors, any of which might affect proper combustion, were incorporated in a single appliance. Merely eliminating, readjusting, or altering a single factor in some instances would correct the fault. Thus in some cases one had a choice of factors which could be changed to accomplish proper combustion. No attempt was made to determine what corrections were necessary for those appliances which would have required new castings or special parts.

Specific shapes or parts, or space relations which have been desginated as wrong, will not necessarily cause an appliance to perform unsatisfactorily. It is usually a combination of factors that interferes with proper combustion. There are numerous designs of different types of appliances with widely varying shapes and space relations, operated under different service conditions, all of which make it impossible to determine their safety and durability without performance or service tests. Faults that are known to contribute to improper aeration of the flame, together with suggestions for increasing adaptablity and safety of appliances, are discussed in the following sections.

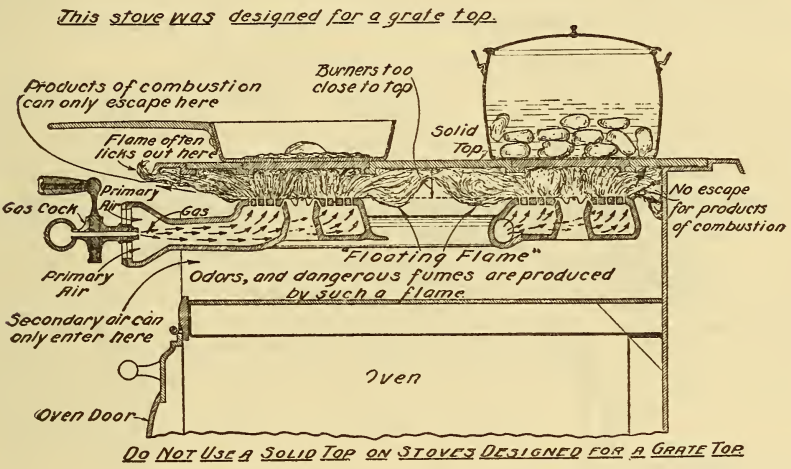
1. COOKING STOVES

Improper combustion by cooking appliances alone did not cause any fatalities nor were any persons rendered helpless. Five persons suffered from ill health from the use of improper solid cooking tops. A hot-plate stove which had burner heads made in two parts, the upper of which was removable, was designed so that improper aeration occurred when the utensil was in place. The stove contributed to the poisoning of three persons.

A solid top used on stoves designed for a grate top results in an insufficient supply of secondary air to all burners and an inadequate provision for the escape of the products of combustion. Secondary air can enter only along the front of the stove which serves also as the only means for exit of the products of combustion. The flame "floats" under such solid tops in the manner shown by the sketch

in Figure 23. When a "floating flame" can be observed it is usually an indication that combustion is incomplete.

This does not mean that gas can not be completely burned under a solid cooking top. There are different designs of solid cooking tops with which proper combustion is possible. Such cooking tops have properly designed burners that are placed the proper distance below the top and the burners are so arranged that the products of combustion from any one burner do not interfere with the flame of another. This is accomplished by making adequate provision for the exit of the burned gases without interfering with the supply of secondary air. The appearance that the flame should have



WRONG.

Fig. 23.—*Appearance of flame when the exit of burned gases and the access of air to the flame is interfered with as by the use of a solid top above burners designed for use with a grid top*

when the combustion is complete is shown by Figure 24. This applies to solid-top stoves and grate-top stoves when utensils are over the burners.

Some hot plates, otherwise called laundry stoves, have burner heads made in two parts; the upper part is not fastened and is easily shifted. This is not a safe type of construction. Many of these burners have an inner and an outer circle of flame. The inner circle of flame is improperly aerated.

So-called "gas savers" made to fit on cooking top burners, which are usually disklike in shape, also cause odors and incomplete combustion, and should not be used.

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Two complaints were received regarding oven burners with flame spreaders of inverted channel shape which caused the formation of a disagreeable odor and some carbon monoxide.

If oven burners are placed too close to the oven bottom, natural circulation may be retarded to the extent that combustion is incomplete. As a result of such construction the burner may become quite hot and thereby reduce the injection of primary air. If the ports are drilled at such an angle that the flame laps back around the burner the excessive heating of the burner may cause it to become red hot. Ultimately oxidation may clog the ports and result in improper combustion.

Unburned gas was found to escape at the air shutter of an oven burner when the gas was partially turned on. The resistance to the

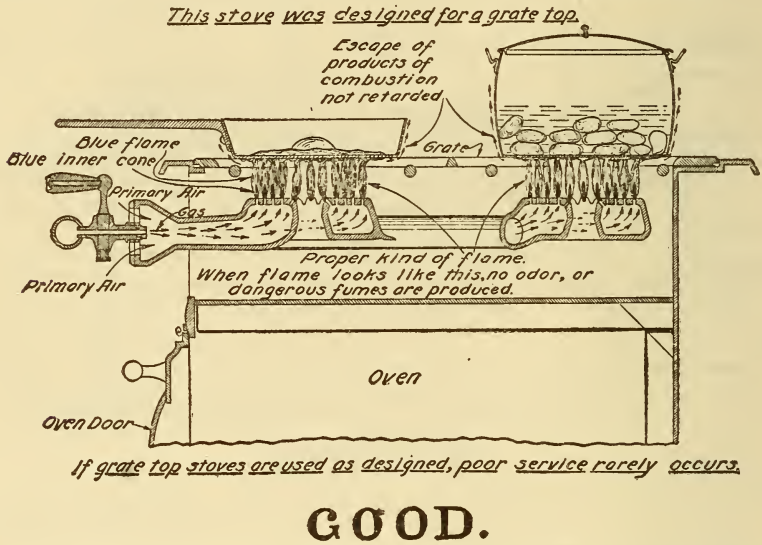

Fig. 24.—*Appearance of a flame of a type which rarely liberates carbon monoxide*

flow of gas through the adjustable orifice dissipated the energy of the gas, and the shape and proportions of the injecting tube of the burner were not such as to favor the injection of primary air. An oven burner should not be made with an injecting tube that has a bend closer to the throat than about six times the throat diameter. The relative proportions that combine to make an efficient injecting tube are shown in Figure 27. Adjustable orifices dissipate the energy of the gas when they are made with small apertures through the adjustable feature and have a large hole and long channel in the cap. Furthermore, small holes in the needle are susceptible to clogging and are not easily cleaned. Clogged orifices sometime contribute to flash back and lead consumers to believe that the quality of the gas is inferior.

2. YELLOW-FLAME ROOM HEATERS

During this investigation no cases of asphyxiations by yellow-flame heaters were encountered. Two different designs of this type of heater were tested and it was found that the combustion was complete. Poisoning by yellow-flame heaters will occur if the aeration of the flame is restricted just as in any other type of gas appliance. A yellow flame can not be "semiconfined" in the same manner as a blue flame, because the aeration of a yellow flame is not as rapid. One objection to yellow-flame heaters is that the tips sometimes become clogged and the flame does not spread from tip to tip, which causes the escape of unburned gas.

3. RADIANT ROOM HEATERS

There are many types of blue-flame room heaters, of which the radiant type is the most important because of its attractiveness and common use. Four cases involving 13 people were investigated where asphyxiations had occurred from improper combustion in radiant heaters. There were three fatalities (two cases) which happened in closed bedrooms. The causes of trouble may be summarized as follows:

(1) An insufficient supply of primary air caused by (*a*) a design which did not provide adequately for primary air even when the appliance was new; (*b*) the clogging of the burner ports by dust, lint, or corrosion; and (*c*) tampering with the air shutter or other adjustments of the appliance by the consumer.

(2) Failure of secondary air to reach the flame in sufficient quantity because the radiant was not properly shaped or not sufficiently open.

(3) Burning the gas at too large a rate for the combustion space available within the radiant, caused by (*a*) the installation of too large an orifice for a radiant of the size employed and the pressure existing on the consumer's premises, or (*b*) changes made by the consumer.

(4) Inadequate provision for immediate access of air to the gas, which was not completely burned within the radiant.

To avoid these difficulties it is necessary to design appliances so that they will not only burn the gas completely when new and under the service conditions existing when they are installed, but they must also have a "factor of safety" to provide for changes which may take place either in the condition of the appliance itself or the conditions of gas service.

It is very important that the burner tips be made of material which will not readily corrode in service, and that they be as much protected from clogging with lint and dust, and made as easy to clean as possible. It is thought best not to provide any means of

easy adjustment, such as air shutters or adjustable orifices, the improper setting of which can possibly lead to a hazard. The ports should be of a size through which the flame will not flash back easily.

Most radiant heaters require that a large percentage of the air necessary for combustion should be injected by the gas as primary air. The percentage of primary air that is injected is affected by the design of the injecting tube, the restrictions in the gas cock, or orifice, the shape and dimensions of the burner head, the port area, etc. The energy of the gas should not be dissipated by a crude injecting tube and a small-bore gas cock, or other restrictions in the gas passage. The burner head usually becomes quite hot and if of large internal area, the heating of the air-gas mixture excessively reduces the injection of air, which may be conducive to oxidation or deterioration of the material at the burner ports, as well as the production of carbon monoxide.

It is usually unsafe to operate a heater when the flame streams from the radiants. It may be caused by (1) insufficient injection of primary air; (2) the burning of too much gas for the size of the radiant; or (3) the radiant is not sufficiently open to permit both the proper exit of burned gases and the access of secondary air to the flame.

Several tests of this investigation showed that more carbon monoxide was produced by a soft flame confined within the radiant than if the flame streamed out. Owing to the fact that odor is rarely detectable when combustion in radiant heaters is improper, one can not judge by this means whether the performance is proper.

A soft flame that is improper for some designs of radiant heaters may be caused by: (1) Clogged burner tips, (2) too small port area, (3) improper injecting tube, (4) an excessively heated burner, (5) low-gas pressure and large orifice, (6) wrong air-shutter setting, and (7) improper gas cock.

The advantage of opening the radiant at the top and providing for access of secondary air from the rear was shown by tests conducted with a radiant heater that produced carbon monoxide even when new and normally operated. The aeration of the flame was augmented by removing the upper half of the back of the radiants. When this was done, secondary air could flow to the top of the radiant from the rear and the heater no longer produced carbon monoxide. Furthermore, the heater was tested when the flame was very soft and streaming from the radiants, which condition was obtained by closing the air shutter, and not a trace of carbon monoxide was produced. A provision for supply of secondary air from the rear undoubtedly increases the factor of safety.

The safe performance of any heating appliance depends largely on the construction of the combustion chamber. It is most essential

that the openings into and from the combustion chamber and the clearance between the burner and the material to be heated is sufficient to allow the circulation of air to the flame. The burner must be designed and spaced in the combustion chamber so that secondary air can flow freely to all ports. The vent on any appliance should not be so located or designed that it may be accidently closed by utensils or other devices.

Several drawings have been prepared which will be of interest to manufacturers of radiant heaters and will be supplied on request. These drawings show some features of design which may contribute to improper and proper performance of the radiant heater.

4. WATER HEATERS

Improper combustion in eight side-arm water heaters contributed to the illness of 23 persons during the period of the investigation. Seven of these persons were completely overcome, but were revived by prompt treatment. There were no fatalities.

The major causes of improper combustion were as follows: (1) Excessive consumption of gas (orifice too large); (2) improper location of baffles; (3) clogged burner ports; (4) diameter of burner head the same as inside of shell, which interfered with aeration of flame; (5) burner too close to copper coils; (6) unequal spacing between inner coil and outer coil and between outer coil and shell; (7) improper arrangement of ports for good aeration of flame; (8) improper setting of air shutter; and (9) operation of unvented heater in small and closed rooms.

Some causes of incomplete combustion and a sketch of the appearance of an improper flame are shown in Figure 25.

The most outstanding fault was found in a water heater which was designed with a burner head of approximately the same diameter as the inside of the shell surrounding the coils. Secondary air could gain access to the flame only through two openings in the central part of the burner. The portion of the flame adjacent to the shell was so deprived of air that the heater could be operated only at about one-half the normal rate of consumption without causing the formation of carbon monoxide. The location, size, and shape of parts which determine either the circulation of air through the heater or its distribution to different parts of the flame are vital factors that enter into the proper design of water heaters. The quantity of gas that can be completely and efficiently burned by a water heater is determined largely by the extent to which such factors affect the manner of aeration of the flame. In a general way the efficiency of side-arm water heaters varies with the length of the tubing and the extent to which excess secondary air is excluded.

Heaters with short coils can be baffled to obtain good efficiency, but are likely to be unsafe in service.

It is not good practice to support the injecting tube of the burner or the mixer by set screws, as shown by Figure 25. Gas was found to

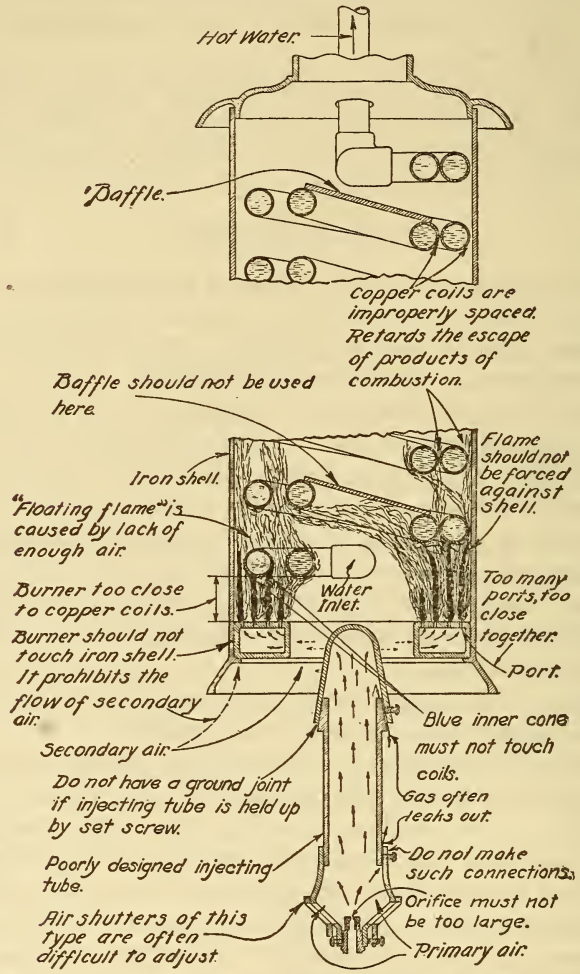

FIG. 25.—*Sketch illustrating faults frequently found in water heaters*

leak from a construction of this type. Furthermore, serious results might occur if either connection should come apart, especially if the heater was in operation. Poorly designed injecting tubes and mixers similar to those shown in Figure 25 are other factors that sometimes contribute to improper combustion.

Suggestions of principles of design which are essential for proper combustion in water heaters of the side-arm type are designated on the drawing of Figure 26. This drawing shows an enlarged area where combustion occurs, as compared with Figure 25, and provides for the flow of secondary air between the burner and the shell. It is recommended that the injecting tube be joined to the burner head by a screw connection or cast solid, unless the injecting tube is supported by the base of the frame. The ports are raised and the upper

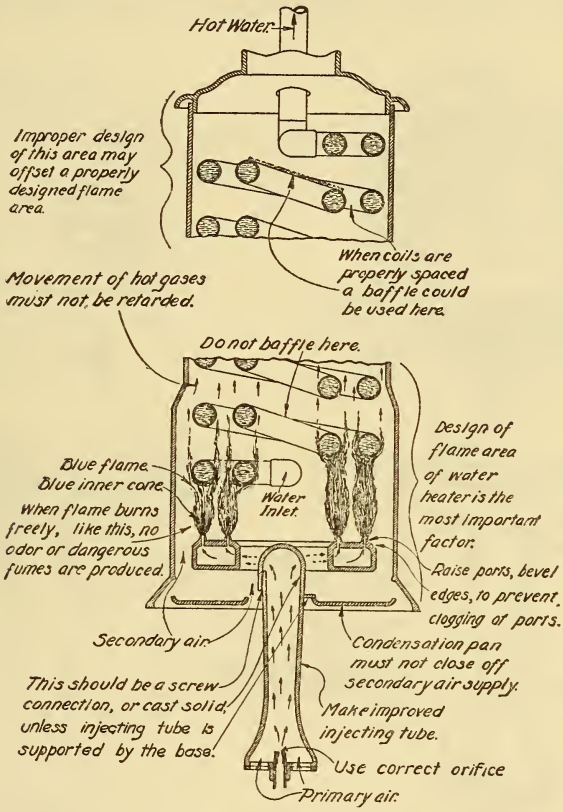

FIG. 26.—*Sketch illustrating some features of good design in water heaters*

edges of the burner head are beveled so that deposits formed on the coils or other matter that may fall on the burner will not readily clog the ports. Clogging of the ports of burners in service is frequently a cause of incomplete combustion. It is important also that the coils be spaced so that foreign matter will not close the horizontal spaces. Spacers should be provided for this purpose.

It will be noted that Figure 26 shows the flame in contact with the coils. The statement is often found in literature, and, there-

fore, commonly believed that when a flame is in contact with a relatively cold surface, such as a copper coil, carbon monoxide is formed. This was found not to be necessarily true. In all the tests of this report it happened that the flame was in contact with the coils, sometimes extending the height of several turns, and in many cases complete combustion was obtained.

Figures 27 and 28 contain suggested designs of burners for obtaining and maintaining good aeration of flame. The arrangement of the ports, the raised ports, and the beveled upper edges of the burner

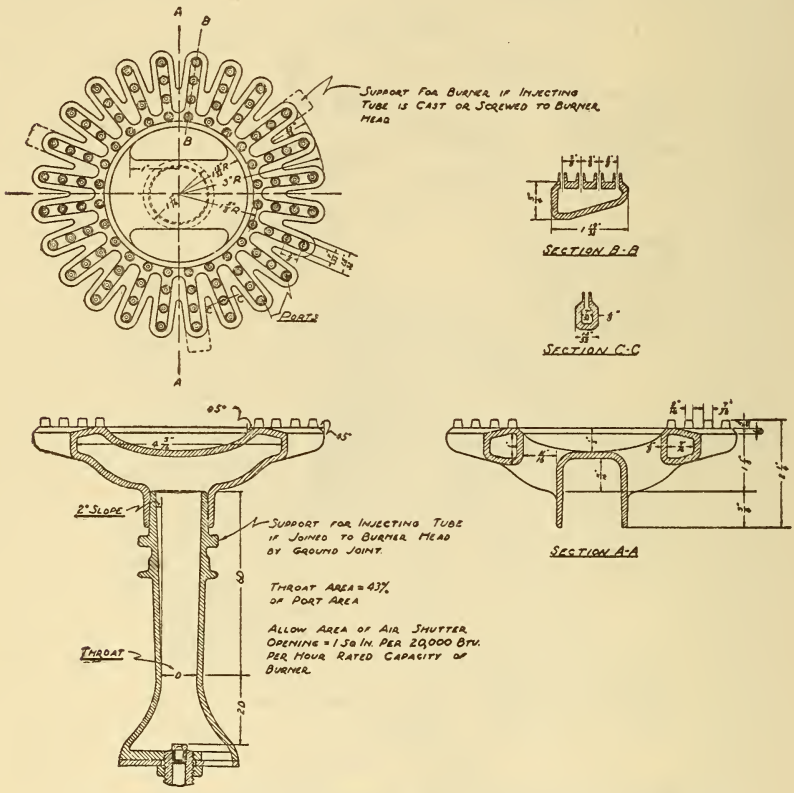

Fig. 27.—*Suggested design for a water heater with 12 radial arms*

head of both proposed designs are intended to minimize the possibility of clogging of ports in service and to greatly aid in the proper aeration of the flame. It will be observed that the arrangement of the ports allows for a beveled edge to extend to the base of the boss of each port. The shape of the injecting tubes shown favors a good supply of primary air.

Because of flash back, burners that are designed with large internal area or with ports of large size are often difficult to light when adjusted for the proper type of flame. If a burner is to be operated in con-

junction with a thermostatic control, it is especially imperative to design to avoid flash backs.

The air shutter should be readily adjustable and contain a means for locking in position.

Water heaters can not, in general, be equipped with a single orifice, which will permit complete combustion and satisfactoy service under all conditions of manufactured gas supply in the United States regardless of heating value, specific gravity, or pressure. When a water

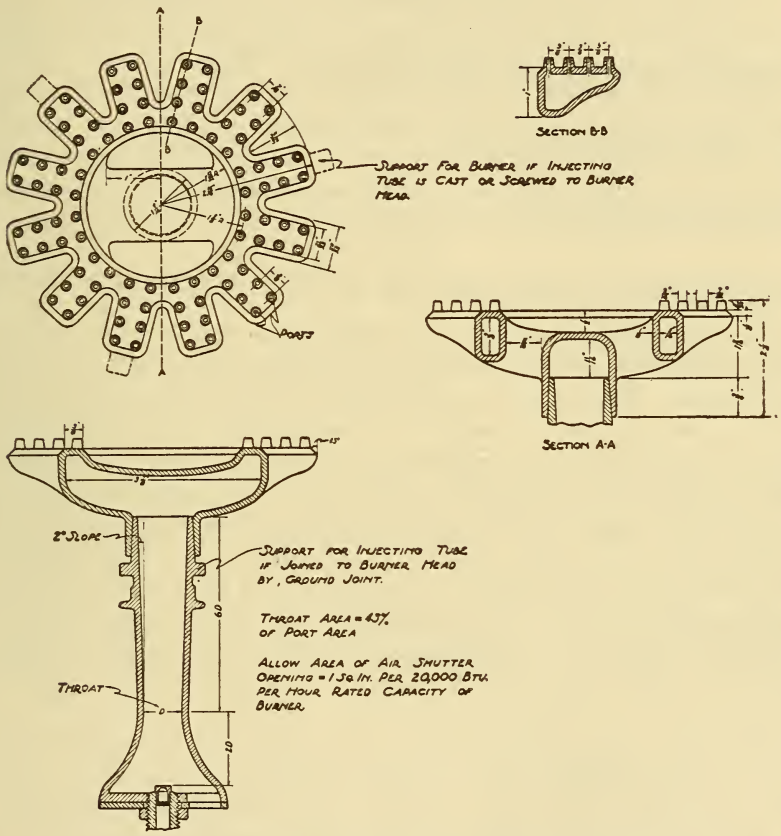

FIG. 28.—*Suggested design for a water heater with 24 radial arms*

heater is installed, care should be taken to see that the orifice is not so large that the gas can not all be burned at any pressure likely to occur.

5. FLEXIBLE TUBING

The extent that flexible tubing contributes to asphyxiations is difficult to determine. When a fatality occurs from escaping gas issuing from disconnected tubing there is often no evidence to prove whether it was accidental or intentional. Tubing, more especially

that of inferior grade, deteriorates unexpectedly, the rubber end pieces may wear and harden, and in time may not firmly grip the connection. Some users are careless. They do not replace tubing that has deteriorated, but continue to use it and sometimes attempt to stop leaks by patches and other unsuccessful methods. Leaks may develop gradually and the user is not cognizant of them. Long lengths of tubing offer considerable friction to the flow of gas, which reduces the pressure of the gas at the orifice of the appliance.

It is well known that rubber deteriorates when exposed to gas or air. It is impossible to tell when the tubing should no longer be used unless it is tested or leaks can be detected in use. The end pieces are often of inferior construction. They are not securely joined to the tubing, deteriorate rapidly, and do not conform to or grip the pipe connection. The American Gas Association has definite performance specifications for tubing, and every purchaser should assure himself that the tubing he uses meets their requirements.

6. OPERATION OF APPLIANCES IN POORLY VENTILATED ROOMS

It can be argued that greater ventilation or positive-flue connections would have prevented most of the asphyxiations which were investigated. Asphyxiations occur mostly in the winter months when it is the custom of many persons to keep windows and doors closed and to depend on natural ventilation for changes of living-room atmospheres. It is a fact that most appliances of all types are unvented and are being operated in rooms of various sizes where the rate of consumption of gas varies widely and the degree of ventilation may vary from good to what may be considered very poor, and only a few asphyxiations occur. This investigation has shown that where asphyxiations occurred, carbon monoxide was produced by the appliances, even when operated in a normal atmosphere (20.9 per cent oxygen).

A few tests were conducted where the object was to duplicate and determine the conditions that caused poisoning in closed rooms. The tests showed that the oxygen content of the closed rooms, heated by gas appliances, was not reduced appreciably after the heater had been operated from two to three hours. Owing to natural ventilation an equilibrium was approached between the rate of entrance of fresh air and the rate of utilization of oxygen. A summation of values of the oxygen content in closed rooms during operation of appliances is given in Table 14.

Of the four cases where appliances were operated for room heating, the lowest value of the oxygen content of the atmosphere, as shown in Table 14, was 18.5 per cent (88.5 per cent of normal). The ventilation in case No. 14 was so good that even after five hours of operation

of the oven of a gas range the oxygen content of the atmosphere was 20.1 per cent (96.2 per cent of normal).

TABLE 14.—*Analyses of the oxygen content of closed rooms during operation of appliances*

Case No.	Rate of consumption		Time of operation of appliance	Oxygen content of atmosphere		Remarks
	Cubic feet per hour	B. t. u. per hour		Per cent	Per cent of normal	
			Hours			
5	30.3	15,150	1	20.1	96.2	Volume of room=1,770 cubic feet; 1 window and 2 doors closed; blue-flame heater operated.
			2	20.0	95.7	
			3	19.9	95.2	
8	31.7	15,850	1	19.1	91.4	Volume of room=2,000 cubic feet; 5 windows and 2 doors closed; radiant heater operated.
			2	18.7	89.5	
			3	18.5	88.5	
10	18.5	9,250	1	19.9	95.2	Volume of room=1,790 cubic feet; windows and door closed; radiant heater operated.
			2	19.4	92.8	
			3	19.3	92.4	
			4	19.2	91.9	
			5	19.1	91.4	
14	[1] 40.0	[1] 20,000	2.5	20.5	98.1	Volume of room=970 cubic feet; 3 doors closed; oven of gas range operated to heat room.
			5	20.1	96.2	
12	60.0	30,000	.17	17.8	85.2	Volume of room=300 cubic feet; 1 door and window closed; water heater operated.
			.33	16.4	78.5	
			.50	15.8	75.6	
			.75	14.9	71.3	

[1] Approximate value.

When one compares these values with those obtained in the unventilated chamber studies, the possibility of asphyxiation from appliances that have well-aerated flames when used for heating an average room seems quite remote. A room heater of the yellow-flame type, as well as one of the blue-flame type, did not begin to produce carbon monoxide until the oxygen content had been depleted to about 16 per cent (76.6 per cent of normal). (See figs. 17 and 19.) No tests of this type were made on a properly adjusted radiant heater which would not produce carbon monoxide in a normal atmosphere. The tests of grate cooking tops with large utensils above the burners, and also the tests of ovens which did not have devices that interfered with the aeration of the flame, showed that the oxygen content was greatly reduced before carbon monoxide was formed.

Four appliances were operated in the unventilated chamber until the flame ceased to burn. The extent to which the oxygen content of an atmosphere may be utilized before a manufactured gas flame is smothered out is believed to depend largely on the design of the appliance and the rate of propagation of flame. The flames of two radiant heaters were smothered out when the oxygen content was about 9 per cent (43 per cent of normal) and 11.7 per cent (56 per cent of normal), respectively. A blue-flame heater ceased to burn

at about 9.4 per cent of oxygen (45 per cent of normal) and the flame of a yellow-flame heater was smothered out at about 11.9 per cent of oxygen (57 per cent of normal). Considering these values of the oxygen content of the atmosphere, that were obtained when the flame ceased to burn, it is believed that complete smothering of the flame of manufactured gas is exceedingly remote unless the room is unusually small, the rate of consumption of gas is exceptionally large, or the ventilation is very poor.

Three series of analyses of the atmosphere at different elevations in an unventilated chamber were made, and the conclusion was drawn that the products of combustion tend to diffuse evenly in a closed room. Marked strata were not formed. (See Table 10.)

The elimination of asphyxiations will not be achieved by advocating greater ventilation where unvented appliances are operated, unless there is great improvement in the installation, adjustment, and maintenance of appliances, and in the design of those features which affect the aeration of the flame.

It is believed that room heaters and cooking stoves that are correctly designed and adjusted can be operated in most rooms, even when closed, and they will not cause the formation of carbon monoxide from depletion of oxygen. It so happens that if the rate of consumption of gas is excessive for the size of the room the temperature of the atmosphere that results will be reasonably uncomfortable to an active person, unless ventilation is augmented or the rate of consumption of gas is reduced. This probably accounts for the relatively few incidents of asphyxiations in proportion to the total number of appliances in use. During the operation of water heaters, however, such a large percentage of the heat is stored in the water that the oxygen content of the average room may be seriously depleted without making the temperature of the atmosphere uncomfortable. Water heaters, even of the best design, should not, therefore, be installed in living or small rooms unless connected to a flue.

However, as a safety and health measure the public should be advised to exercise care and provide for ventilation during the use of any fuel-burning appliance, especially when the burned gases are liberated into the atmosphere of an inhabited room. Under no condition should a person sleep in a closed room when a fuel-burning appliance is in operation unless the products of combustion are conducted from the room through an adequate flue.

7. EFFECT OF SERVICE CONDITIONS

The oxygen from a definite volume of air is required to completely burn a definite volume of gas of a given heating value. Practically every type of appliance has a definite maximum limit of the quantity

of gas that can be completely burned. With blue-flame appliances the limit varies primarily with the type of the flame; that is, it is dependent upon the primary air that enters the burner. When designing an appliance to accomplish complete combustion, any factors that affect the rate of supply of potential heat in the gas or the rate and manner of supply of primary or secondary air to a flame are of the utmost importance. Consequently an appliance in order to be useful in many localities must be designed to meet considerable variations in service conditions (gas-line pressure, heating value, and specific gravity of the gas).

Appliance manufacturers should equip their product with the proper size of orifice for the service standards where it is to be used, unless the appliance is to be installed by a competent gas fitter who is prepared to insert the proper size of orifice. The correct adjustment of primary air for the service conditions to be met must likewise be provided for.

The gas pressure, heating value, or the specific gravity should not be permitted to vary widely, because a variation of any one causes a variation of the rate of demand for oxygen required for combustion. If the variation is great, flash back may occur or the quantity of gas that can be completely burned by some appliances may be exceeded. It is for this reason that public service commissions and gas companies have cooperated in the establishment of standards for service and reasonable tolerances that may be permitted.

VIII. CONCLUSION

Accidents from carbon monoxide in Baltimore were largely due to improperly designed appliances that had been somewhat recently put into service. There were some appliances that appeared to be of good design when new which had vital parts that would not remain intact with reasonable use. A large percentage of the accidents could be attributed primarily to the acts or carelessness of uninformed persons. It is imperative that manufacturers of appliances seek to correct improper designs and cooperate with the gas industry to arrive at some plan which will be effective in reducing the number of asphyxiations and the cases of chronic poisoning.

Service conditions should be carefully regulated by gas companies to meet the requirements of the appliances in use. Only by such cooperation as this between the gas and appliance industries can safe and efficient service to the public be realized.

The entire industry realizes that if all gas appliances were designed for and used with proper flue connections which were at all times positive there would be comparatively few cases of carbon

monoxide asphyxiations. But the need for a requirement so drastic is open to serious question and would involve hardship to many people.

Existing buildings are not constructed with flues in all rooms. When the cost of remodeling buildings to provide flues is considered, the idea of heating individual rooms with space heaters, for example, is abandoned. In some localities consumers are not in favor of laws requiring flue connections because the expense of providing flues is too great, and thus they would be deprived of many of the conveniences of gas fuel. There are so many appliances giving satisfactory service without flue connections that the public frequently does not consider it necessary to vent appliances, except those that consume gas at an excessive rate in proportion to the size of the room where they are installed. The advisability of laying too much stress on the safety gained through flue connecting small appliances is quite questionable in view of the uncertain action of some flues, particularly when the flue pipe is of small diameter or too long, or has too many bends, all of which may interfere with proper draft.

It requires a specially trained person to determine by inspection when appliances are properly installed, properly adjusted, and in proper condition for operation. If systematic inspection of all gas appliances were provided, the public through ensuing contacts would gradually learn to exercise more intelligence in the operation and care of appliances, many improperly designed appliances would soon be discarded in favor of proper designs, complaints about gas service would be relatively few, and the possibility of serious poisoning from carbon monoxide would be very remote.

The Consolidated Gas Electric Light & Power Co. of Baltimore maintains a completely equipped laboratory for the testing and inspection of appliances. All types of appliances sold by the company are approved by the laboratory. The company also maintains a school for instructing fitters in the proper installation and adjustment of appliances. The example of this company is to be generally recommended to others.

Most appliances of faulty design can be readily remodeled to improve their safety and range of operation. Many appliance manufacturers are in need of technical assitsance to make proper designs, designs that will result in complete combustion of the gas when the appliance is new and will tend to prevent the possibility of clogging or failure of parts from years of reasonable service. Correct information for the manufacturer and the public should be freely disseminated. As these important problems are solved and put into practice, heating by gas will expand and gas will remain the most desirable fuel.

IX. ACKNOWLEDGMENTS

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The cooperation and assitance of the Consolidated Gas Electric Light & Power Co. greatly expedited and broadened the investigation. All the facilities of the company that were needed were available at all times. The testing equipment in the laboratories at Front Street and Spring Gardens was used to make many of the tests.

The Bureau of Standards had studied utilization problems for a number of years. The information gained at the bureau was of much help throughout the investigation, and the author gratefully acknowledges indebtedness to his associates, W. M. Berry, J. H. Eiseman, G. F. Moulton, and G. B. Shawn.

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