CHAPTER 4

Combustion

It must be evident that a thorough knowledge of combustion is necessary for the oil burner man to properly adjust an oil burner for best efficiency and to correct any troubles arising from faulty furnace or chimney conditions.

Ques. What is combustion?

Ans. Rapid oxidation.

Ques. What is oxidation?

Ans. The act of combining with oxygen, or subject to the action of oxygen, or of an oxidizing agent.

Ques. Where is the oxygen obtained?

Ans. In the air.

Ques. How much oxygen is contained in the air?

Ans. 20.91 per cent by volume; 23.15 per cent by weight.

Ques. What is the substance called which is capable of combustion?

Ans. The combustible.

Ques. What is the oxygen called?

Ans. The supporter of combustion.

Ques. What are the two principal elements in fuel oil?

Ans. Carbon and hydrogen.

Kunitz gives for light fuel oil (in per cent); Carbon 84.; hydrogen 12.8; nitrogen 1.5; oxygen 1.4; sulphur 0.3.

Carbon.—A combustible element, non-metallic and present in most organic compounds.

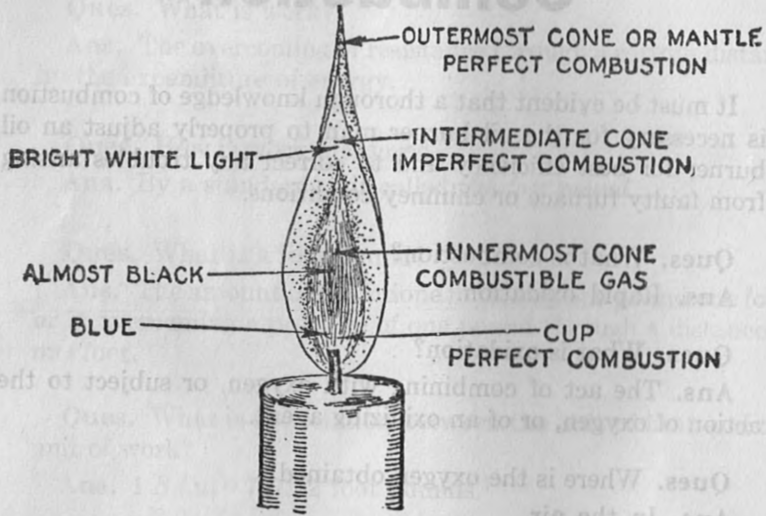


FIG. 1—The candle flame illustrating combustion.

Hydrogen.—A colorless, odorless, tasteless gas; lightest body known.

Sulphur.—An elementary mineral substance of a yellow color, brittle, insoluble in water, easily fusible and inflammable. It burns with a blue flame and gives off a peculiar suffocating odor.

Nitrogen.—A gas possessing mainly negative properties, being odorless, tasteless, colorless, non-combustible and a non-supporter of life or combustion.

Ques. What negative result is due to nitrogen?

Ans. A considerable amount of the heat developed by combustion is used up in raising the temperature of the nitrogen. That part of this heat which is not extracted usefully afterwards is a dead loss.

Ques. What other objectionable effect is due to the presence of nitrogen?

Ans. It sets a low limit to the temperature that may be reached by combustion in air.

Ques. How may the nitrogen heat loss be reduced?

Ans. By cutting down excess air admitted to the burner to a minimum.

Ques. What is the ignition or kindling point?

Ans. That temperature which will cause a combustible to unite with oxygen and cause combustion to take place.

Ques. What happens when combustion takes place?

Ans. The two principal elements, carbon and hydrogen have an affinity for oxygen. When they unite heat is produced.

The oxygen having the stronger affinity for hydrogen, unites with it first and sets the carbon free. A multiplicity of solid particles of carbon thus scattered in the midst of burning hydrogen are raised to a state of incandescence.

Ques. What happens to the carbon?

Ans. It unites with the oxygen, forms carbon dioxide (CO_2) or carbon monoxide (CO).

Ques. What happens to the hydrogen?

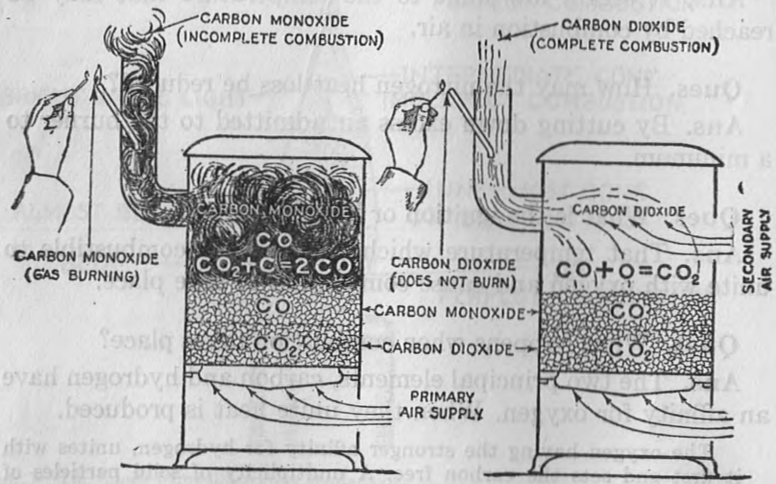
Ans. It unites with the oxygen in the proportion of two atoms of hydrogen to one atom of oxygen, forming water (H_2O).

Ques. When is combustion complete?

Ans. When the combustible unites with the greatest possible amount of oxygen, as when one atom of carbon unites with two atoms of oxygen to form carbon dioxide (CO_2)—sometimes called carbonic acid.

Ques. When is combustion incomplete and why?

Ans. When the combustible *does* **not** unite with the greatest



FIGS. 2 and 3—Combustion in an ordinary stove illustrating ***incomplete*** and ***complete*** combustion.

possible amount of oxygen, as when one atom of carbon unites with one atom of oxygen to form carbon monoxide (CO).

The reason is that the carbon monoxide may be burned further to carbon dioxide (CO_2).

Ques. What other name is given to carbon monoxide?

Ans. Carbonic oxide.

Ques. What causes incomplete combustion?

Ans. Insufficient supply of air.

Ques. What happens when too little air is admitted to the fire?

Ans. There will not be enough oxygen present to supply two atoms of oxygen to each atom of carbon liberated, hence carbon monoxide will be formed, having a heating value of 4450 *B.t.u.* instead of carbon dioxide which has a heating value of 14,544 *B.t.u.*

Ques. What happens when too much air is supplied?

Ans. Since carbon cannot combine with oxygen in any greater ratio than two atoms of oxygen to one atom of carbon, any excess air supply simply dilutes the gases and cools the furnace.

Ques. What is the usual effect of nitrogen contained in the air supply?

Ans. It prevents too rapid combustion.

Ques. Is it possible in practice to obtain perfect combustion with the theoretical amount of air?

Ans. No.

Ques. Is as large an excess of air required for oil as for coal?

Ans. No.

Ques. What is the product of perfect combustion of carbon?

Ans. Carbon dioxide (CO_2).

Ques. How is the state of the combustion in a furnace determined and why?

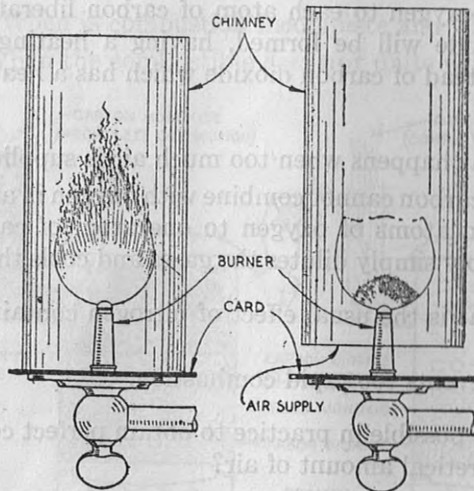
Ans. By determining the amount of carbon dioxide (CO_2) in the flue gases, because carbon is the principle constituent of the fuel.

Ques. What is the visible indication of incomplete combustion?

Ans. Smoke.

Ques. What are the black particles in smoke?

Ans. Solid carbon.



FIGS. 4 and 5—Cause of smoke. When the supply of oxygen is insufficient to consume the particles of solid carbon, they are set free and then assume the form of soot, the collection of these minute particles being called smoke.

Ques. Since smoke may be visible or invisible, what does colored smoke indicate?

Ans. Incomplete combustion.

Ques. What is the Orsat or CO_2 test?

Ans. A test with apparatus, such as shown in fig. 7, to determine the amount of carbon dioxide contained in the flue gases and the amount of excess air which is an indication of the amount of fuel being wasted.

The process of Combustion.—During combustion the more complex compounds of the oil, "*crack*", that is, they break down into simpler compounds and in so doing, free carbon is formed. This free carbon immediately burns to completion in the flame if the proper amount of air has been thoroughly mixed with the oil and the temperature of the flame be not lowered by contact with relatively cool surroundings.

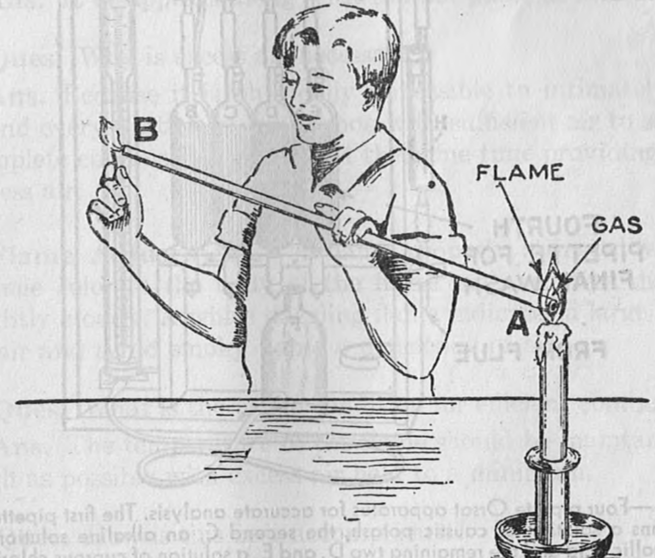


FIG. 6—Experiment showing that combustion occurs only at the surface of an ordinary flame. Insert one end of a small open tube into the flame. The combustible gas then will escape at the other end and can be lighted with a match.

Ques. What happens if the flame be cooled?

Ans. Some of the carbon burns to carbon monoxide (CO) or, in extreme cases, does not burn at all, but is deposited as free carbon (soot).

Ques. What is the nature of the carbon monoxide?

Ans. It is a combustible gas and when supplied with oxygen adequate temperature will burn forming CO_2.

Fig. 1 shows graphically what happens during combustion.

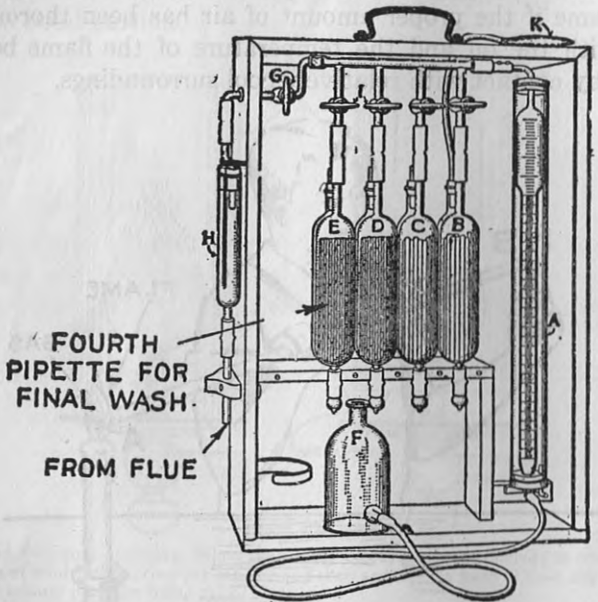


FIG. 7.—Four pipette Orsat apparatus for accurate analysis. The first pipette B, contains a solution of caustic potash, the second C, an alkaline solution of pyrogallic acid and the remaining two D, and E, a solution of cuprous chloride. Each pipette contains a number of glass tubes, to which some of the solution clings, thus facilitating the absorption of the gas. In the pipettes D, and E, copper wire is placed in these tubes to re-energize the solution as it becomes weakened. The rear half of each pipette is fitted with a rubber bag, one of which is shown at K, to protect the solution from the action of the air. The solution in each pipette should be drawn up to the mark on the capillary tube. The various operations are performed the same as with the three pipette apparatus with the exception that after the gas has been in pipette D, it is given a final wash in E, and then passed into the pipette C, to neutralize any hydrochloric acid fumes which may have been given off by the cuprous chloride solution, which, especially if it be old, may give off such fumes, thus increasing the volume of the gases and making the reading on the burette less than the true amount.

Ques. What are the products of combustion?

Ans. 1. Product of complete combustion CO_2; 2, product of incomplete combustion CO; 3, product of burned hydrogen, steam or H_20; 4, excess air, unused oxygen; 5, nitrogen.

Ques. What happens to the water resulting from the combustion of hydrogen and oxygen?

Ans. It disappears along with the hot gases as steam.

Ques. Why is excess air necessary?

Ans. Because it is physically impossible to intimately surround every particle of the carbon with sufficient air to sustain complete combustion without at the same time providing some excess air.

Flame Adjustment.—A flame properly adjusted will be orange color in the body of the flame with red tips that are slightly cloudy. A white dazzling flame indicates a large excess of air and a red smoky flame a deficiency of air.

Ques. What is the prime condition for efficient combustion?

Ans. The temperature of the flame should be maintained as high as possible with excess air held to a minimum.

Ques. How is this best accomplished?

Ans. By burning the flame in a combustion chamber of a refractory material.

Ques. Does the color of the flame indicate with precision the correct burner adjustment for most efficient combustion?

Ans. No, but, an experienced oil burner man can approximate the best adjustment by flame color. However, for precision, a CO_2 test should be made with Orsat outfit.

Radiant Heat.—As an example, the sun gives off pure radiant heat, but when the sun is beclouded, the heat transfer is considerably reduced.

The superior efficiency of a radiant flame in a furnace box is obvious. That is, it crams it full of heat. According to Kennedy Van Saun: It is agreed by those familiar with combustion that radiant heat is about eight times as good as heat by convection in the combustion chambers.

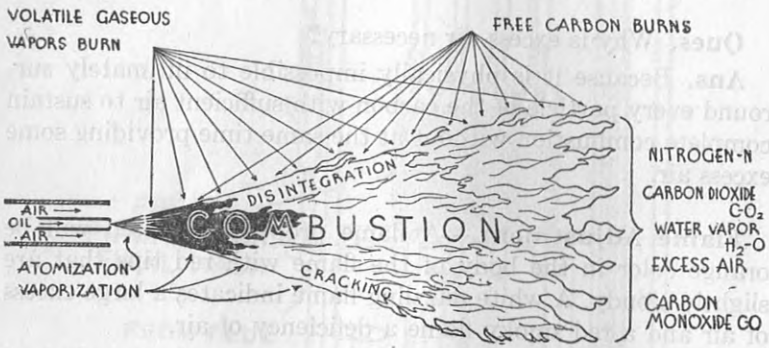


Fig. 8—Combustion diagram. Sprayed oil upon entering the high temperature zone vaporizes, and the lighter gaseous vapors burn readily. The heavier vapors "crack" (disintegrate) giving off light vapor and free carbon which is carried in suspension until burned. The luminous flame travels until combustion is arrested by lack of oxygen or because of the complete burning of the carbon.

Air Adjustment.—This is important in obtaining efficient fire. A minimum of approximately fifteen pounds of air is required to support the combustion of one pound of oil.

Ques. What are the conditions conducive to efficient combustion?

Ans. There must be the proper amount of air and the proper mixing of the air with the sprayed oil.

Ques. How should the air be introduced?

Ans. It should be introduced in such manner as to thoroughly mix with the sprayed oil, producing a churning action, thus creating a state of *"turbulence"* throughout the flame.

The Object of Refractory.—For highest combustion efficiency, the oil flame must be surrounded as nearly as possible with refractory material which reaches a relatively high temperature shortly after the burner starts.

Ques. What duty is performed by the refractory material?

Ans. It receives the heat transferred to it by convection from the hot gases. The radiant energy from the refractory material then crosses into the combustion zone from all angles, bombarding the air and oil particles from all sides, thus creating the proper temperature conditions for highest combustion efficiency.

Flame Placement.—The zone of highest temperature of a flame is at the tip. Fig. 9 shows a carefully conducted experiment.

An ordinary kerosene lamp flame was supplied with just enough air to produce an orange colored flame, free from smoke. Note that ⅛ inch from the flame, the temperature was but 340° Fahr. as compared with 720° at one inch beyond the tip of the flame. Heat transfer by *radiation* was the principal factor producing temperature by the side of the flame' while both *radiation* and convection were factors above the flame.

Ques. What does this experiment show?

Ans. It would seem reasonable that for the highest efficiency in the placing of a flame in a furnace, the low temperature base of the flame should be placed low down, even below the heat absorbing surface of the boiler.

Ques. Why?

Ans. By so doing, it is possible to bring the tip of the flame, so that it terminates as early as possible in the travel toward the stack.

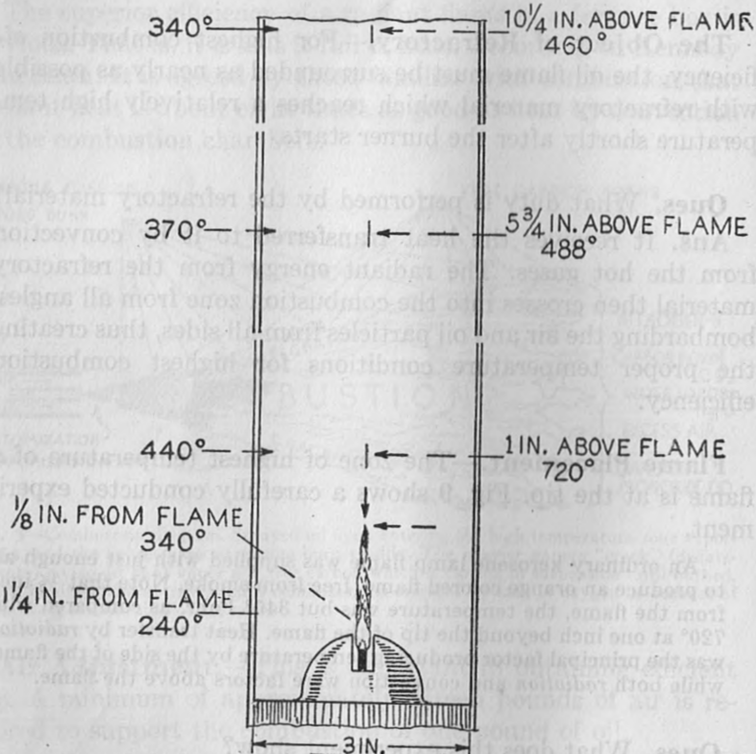


FIG. 9—Experiment illustrating flame placement.

Ques. What does this accomplish?

Ans. It allows for the maximum time for the transfer of heat to the boiler, and exposes a maximum amount of boiler surface to the zone of high temperature.