In this process, a sand mold is built around the pieces to be welded and the metal poured in this. The mold is made of sand and clay, which should be mixed thoroughly stiff and as dry as possible, as the less moisture there is in the mold the better will be the results obtained. For this reason the mold should be dried in a furnace or oven at a low temperature for from six to eight hours. To test the dryness of the mold, two or three wires can be rammed up in the thickest section of it and these pulled out after drying to see if any moisture remains.

With the mold completed the thermit is placed in a special receptacle which is located over the mold. The thermit consists of aluminum and oxide of iron. A little ignition powder is placed in this and lighted with a match. Immediately there sets up a tremendous chemical action, which produces a superheated liquid steel and superheated liquid slag consisting of aluminum oxide. When the mass is entirely molten it attains a temperature of 5400° F. The bottom of the receptacle is then tapped and the liquid metal runs into the mold and into and around the joint to be welded. The high temperature of the liquid mass causes the ends of the pieces to be welded, to become molten and pasty, and fuse with the thermit.

Welds were made with this process on a bar of rolled steel, 2 by 4½ inches, which was broken, then welded, and afterwards tested. The tests showed an efficiency of 97% in tensile strength and 88% in elastic limit.

The greatest usefulness of this method of welding is for the stern frames of steamships which have broken, locomotive side frames, driving wheels, connecting rods, and other things of a similar nature, but the building of the mold makes it commercially prohibitive where autogeneous or electric welding can be used economically.

CHAPTER VIII

Furnaces and Fuels Used for Heat-Treatment

In working steels it is very important that they be properly heat-treated, as poor workmanship in this regard will produce working parts that are not good even though the stock used be the highest grade of steel that is procurable. And by improperly heat-treating them it is possible to make high-grade steels more brittle and less able to support a load or withstand stresses than ordinary carbon steels. All steels are improved in tensile strength, elastic limit, elongation, or reduction of area by annealing, hardening, or tempering them. The different treatments are divided into three distinct classes, the first of which is hardening, the second annealing and reheating, and the third case-hardening, carbonizing, or cementing.

The theory of heat-treatment rests upon the influence of the rate of cooling on certain molecular changes in structure occurring at different temperatures in the solid state. These changes are of two classes, critical and progressive; the former occur periodically between certain narrow temperature limits, while the latter proceed gradually with the rise in temperature, each change producing alterations in the physical characteristics. By controlling the rate of cooling, these changes can be given a permanent set, and the physical characteristics can thus be made different from those in the metal in its normal state.

The results obtained are influenced by certain factors as follows: First, the original chemical and physical properties of the metal. Second, the composition of the gases and other substances which come in contact with the metal in heating and cooling. Third, the time in which the temperature is raised between certain degrees, or the temperature-rise curve. Fourth, the highest temperature attained. Fifth, the length of time the metal is maintained at the highest temperature. Sixth, the time consumed in allowing the temperature to fall to atmospheric or the temperature-drop curve.

The third and sixth are influenced by the size and shape of the piece; by the difference in temperature between it and the heating and cooling mediums, and by the thermal capacity and conductivity of the latter. Each of these may vary widely within the temperature range to which the piece will be subjected.

The first, second, third, and fourth are but elements of the heating process, and the sixth of the cooling. The method of heating the alloy steels is very important, as mechanical injuries are liable to occur, in the external layers of the metal as well as the internal, from a too rapid rise in the temperature, especially at the start.

The highest temperature to which it is safe to submit a steel for heat-treating is governed by the chemical composition of the steel, and this temperature should be about 40° F. above the highest point of transformation in the steel considered. This pure carbon steel should be raised to from 1450° to 1650° F., according to the carbon content, while some of the high-grade alloy steels may safely be raised to 1750° F., and the high-speed steels may be raised to just below the melting point. It is necessary to raise the metal to these points so that the desired change in structure will be secured. If raised far above these temperatures in an oxidizing atmosphere, the surface of the piece becomes covered with a scale of iron oxide and oxidation extends to the elements combined with the iron.

When these oxides remain within the metal, they tend to form a film of separation between the metallic grains, thus destroying the cohesion between them, and the metal is said to be burned. After burning, it cannot be brought back to its former strength without remelting. If the temperature is maintained within the crystallogenic zone, disaggregation proceeds, so that the longer it is subjected to this temperature and the higher the temperature, the less homogeneous it becomes and the coarser its grain after cooling. Steel in this state is called over-heated. It can be partially returned to its former strength by repeated forging when heated above the critical temperature, followed by positive quenching, or it may be restored by a proper method of heat-treating.

When, as always happens, the grain has become coarsened by overheating it must be refined again to bring it back to its original condition. To do this it is necessary to heat the metal to the point where a new crystal-size is born, as the coarsening of the grain is merely a growth of the crystals, and these crystals grow with every increase in the temperature above the point necessary for hardening or annealing. If we barely pass the degree of temperature at which this new crystal-size is born we will obtain the smallest grain size that the steel is capable of. This temperature varies with the carbon content of the steel. The higher the percentage of carbon the lower the degree of temperature that will be required; a low-carbon steel must be heated to 1650° F., a 0.40% carbon steel to 1475° F., and so on. Some of the special alloying materials also affect this temperature as well as the size of the grain.

FURNACES AND THEIR FUELS

Owing to the nature of most steels they must be handled very carefully in the processes of annealing, hardening, and tempering; for this reason much special apparatus has been installed in the past few years to aid in performing these operations with definite results. This apparatus is divided into two distinct classes; that is, the apparatus for heating the metal, and that for cooling. In heating the metal four methods are used; namely, furnaces using solid fuel, liquid fuel, gaseous fuel, and electricity.

The forge fire was at first used for burning solid fuels, such as coal,

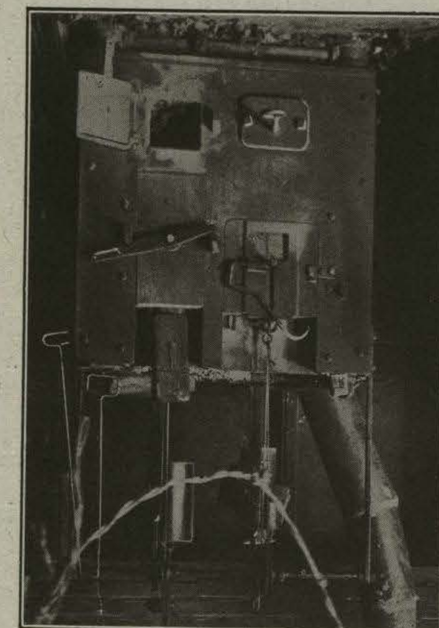

Fig. 77. — Hard fuel furnace for heat-treating steel.

coke, charcoal, etc., to heat metals. From this developed the enclosed furnace, as shown in Fig. 77, and consequently these are the most numerous. In the furnace is a grate on which to burn the fuel, and over this an arch to reflect the heat back to a plate on which the work is placed. This plate should be placed so that the flames will not come in contact with the pieces of metal to be heat-treated. For this reason cast iron or clay retorts are sometimes used in the furnace to place the work in, while the necessary heat is obtained by the flames encircling these. They only have an opening on one side, and this is placed opposite the front door, so the work can be easily passed in and out. The oxidation, sulphuration, etc., that spoil the smooth surfaces of the work, and are largely caused by the products of combustion of the hard fuels, are thus eliminated as much as possible with this kind of furnace and fuel. With this furnace it is necessary to keep the heat in and the cold air out as much as possible, and therefore the doors should open and close very quickly to aid in the rapid handling of the work. For this reason the sliding doors with counterbalancing weights, as shown, should be used.

The disadvantage of this style of furnace is that it is almost impossible to keep a constant temperature, and as a chimney must be provided, much heat is lost through that. By not being able to keep a constant temperature, it is impossible to measure the heat with a pyrometer, and the heat must be judged entirely by the color, as seen with the eye, and this makes the results depend entirely on the skill and experience of the workman. Also the atmospheric air or gases generated by combustion or a mixture of both come in contact with the hot metal. These are liable to cause the metal to lose some of its carbon content, especially at corners or on thin delicate sections, from the oxidizing influence of the oxygen in the air. The fuel is also liable to contain injurious ingredients, such as sulphur, which may enter the steel.

LIQUID FUEL

Furnaces that use a liquid for fuel, such as crude oil, kerosene, gasolene, naphtha, etc., are becoming more numerous every day, owing to the ease with which the fire is handled and their cleanliness as compared with a coal, coke, or charcoal fire.

Crude oil and kerosene are the fuels generally used in these furnaces, owing to their cheapness and the fact that they can be obtained nearly everywhere. The adoption of oil for fuel has resulted in a considerable saving in the fuel bill over that of the coal-burning furnaces, and has also made a big improvement in the cleanliness of the hardening room. In fact, where natural gas is not obtainable at about one-quarter of the usual price of city gas, crude oil is by far the cheapest fuel that can be obtained for heat-treating furnaces. An exception to this might be made in the future when considering producer gas, but at present enough data has not been obtained by which to draw comparisons.

One of the simpler of these oil-burning furnaces is shown in Fig. 78. With any of the oil furnaces gas can be used as a fuel by merely changing the burners. With a properly designed furnace the temperature can be raised quickly to the point desired; can be maintained at this temperature for any length of time, and an even heat can be kept throughout the entire chamber of the furnace. With the proper fuels and valve for regulating this, the temperature in the furnace can be raised or

lowered as rapidly or as slowly as necessary for the different kinds of work. In the annealing of metals also the rate of cooling can be made as slow as needed if the proper equipment is installed. All of this can be accomplished without the customary smoke, soot, ashes, dust, gases, and foul odors that are met with in hardening rooms where the old hard fuel furnaces are used. The saving in the time consumed by the operator in running the furnace is also an important factor, as when the proper temperature is once obtained and the valves set, practically no time is required for this part of the work.

The installation of the furnaces and their necessary equipment is very important for the proper operation of the same. For safety, it is best to have the fuel supply in a tank outside of the building and pipe it, underneath the floor, to the furnace. As a blast of air is necessary, this can also be piped, under the floor, from the fan, blower, or air compressor. The air and fuel pressures must be steady and uniform, and there must be volume enough to give the furnaces their proper temperature and maintain it at the point desired. This, of course, varies with the kinds of material to be heated.

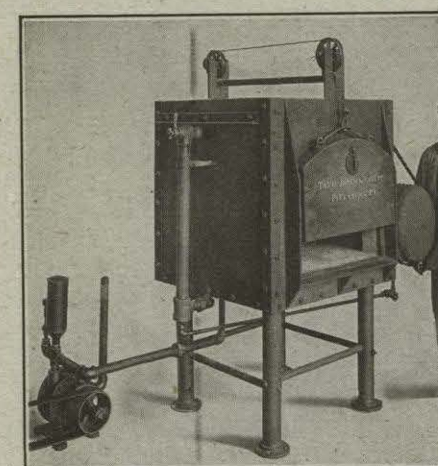

FIG. 78.—Oil-burning, annealing, tempering, and hardening furnace.

Where accurate temperature control is not necessary, and pressure under 14 ounces will suffice, a steel fan or pressure blower, that will give the proper volume, will do the work. Where pressures from 2 to 5 pounds are required the positive pressure blower is needed, and when an air pressure above this is necessary a compressed-air plant will be needed. In some cases good dry steam will give better results at a high pressure and effect a saving in the fuel. In that case steam pipes take the place of the air pipes, and these connect up to the steam supply. The quantity of fuel needed varies with the temperature required, material treated, and speed at which it is handled, but the fuel pressure must always be uniform. For the oil 5 pounds pressure is sufficient.

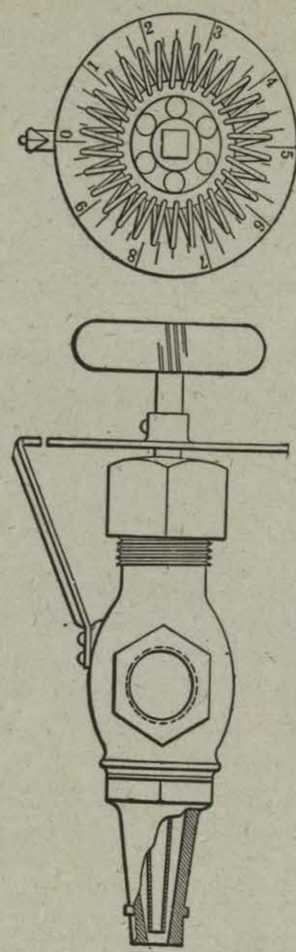

FIG. 79.—High-pressure oil burner.

In some cases between the tank and furnace is located a coil of pipe through which the fuel flows and over which a stream of water is flowing to keep the liquid at a low, even temperature when it enters the burners, which are located in the furnace.

The burner to be used is an important factor in economical production, and it is not practical to have one burner that will do all kinds of

work. Whether high or low pressure air or steam is to be used for the blast makes a difference in the kind of burner that should be used to get the greatest efficiency with the minimum fuel consumption, as well as the temperature that it is necessary to maintain in the forge, and the nature of the work that is to be done. In Fig. 79 is shown a good design of high-pressure oil burner.

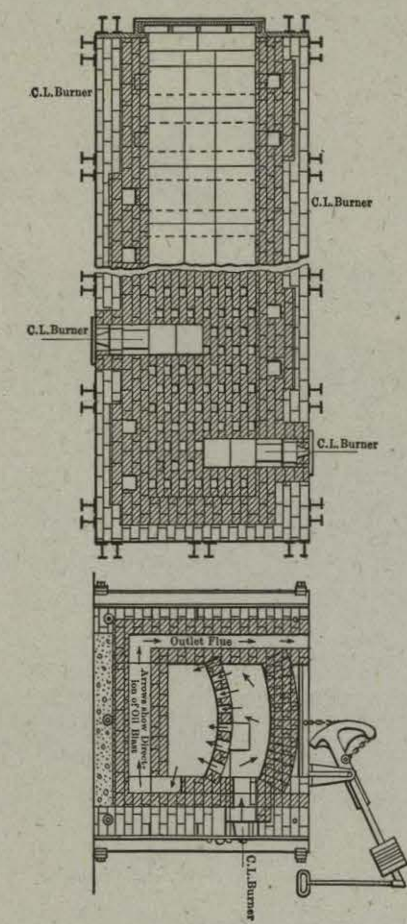

FIG. 80. — Details of construction of over-fired furnaces.

The dial with the figures and the pointer at the bottom have been added for fine adjustment. The sectional view at the tip shows the method of controlling the volume of atomized oil that is injected into the furnace.

With this fuel hardly any work is required to keep up the fires, as they can be lighted in the morning and the temperature regulated by the turning of a few valves and cocks. A more even temperature can thus be kept in the furnace than with the solid fuels, but the opening of the doors to handle the work reduces the temperature of the furnace the same as with the solid fuels. The action of the gases of combustion or the oxygen of the atmosphere in attacking the hot metal gives the same disadvantages.

The furnaces are built in the over-fired and the under-fired type. In the over-fired furnace, as shown in Figs. 80 and 81, the atomized gas from the oil burner is sent into an opening over the heating chamber that is separated from it by an arch. Here the gas is burned and passes

FIG. 81. — Small over-fired furnace.

through numerous openings in the arched roof of the heating chamber, as indicated by the arrows in the right-hand view in Fig. 80. The burned gases then pass out through holes in the side of the heating chamber, close to its floor; then under it and up through flues on the opposite side.

Thus the entire heating chamber is uniformly filled with the products of combustion and the spent gases utilized to heat the floor of the working chamber. This gives a soft uniform heat throughout the working chamber, and the temperature is so easily raised, lowered, and controlled that overheating or burning the metal can only result from gross carelessness.

This uniform heat in the heating chamber also reduces to a minimum the distortion and warping that results from uneven heating, and a more even hardness can be obtained throughout the piece than can be produced with a hard fuel or under-fired furnace.

With the proper fuel supply and valves to control the same, the temperature of the heating chamber can be maintained for an indefinite period, within 25° F. of any temperature between 600° and 2000° F.

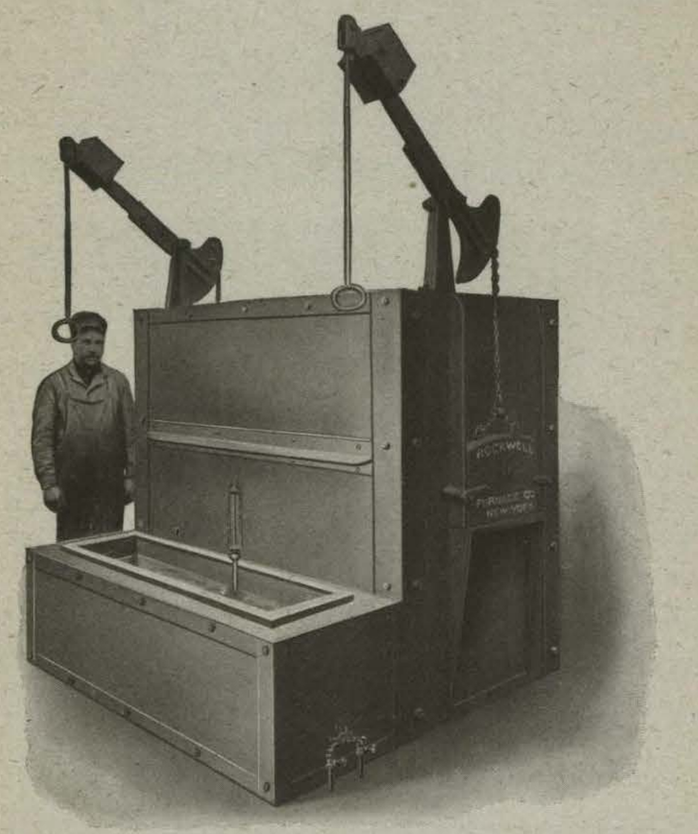

FIG. 82. — Double-end furnace with tank for quenching bath attached.

On test runs of $1\frac{1}{2}$ hours each, at certain temperatures, the variation was not over 10 degrees.

For high-grade alloy steels, where the most accurate results are required, the muffle furnace should be used, in order to avoid the action of the products of combustion on the metal, since it is liable to absorb some impurities from the gases. These impurities might weaken the metal and leave it less able to withstand the strains and stresses put upon it than would be the case if the metal were protected from them. For ordinary work, however, the injury is so slight it can be overlooked, and the fuel consumption is much lower in the oven than in the muffle furnace.

A furnace open at both ends, wth a tank attached to hold the quenching bath, is shown in Fig. 82.

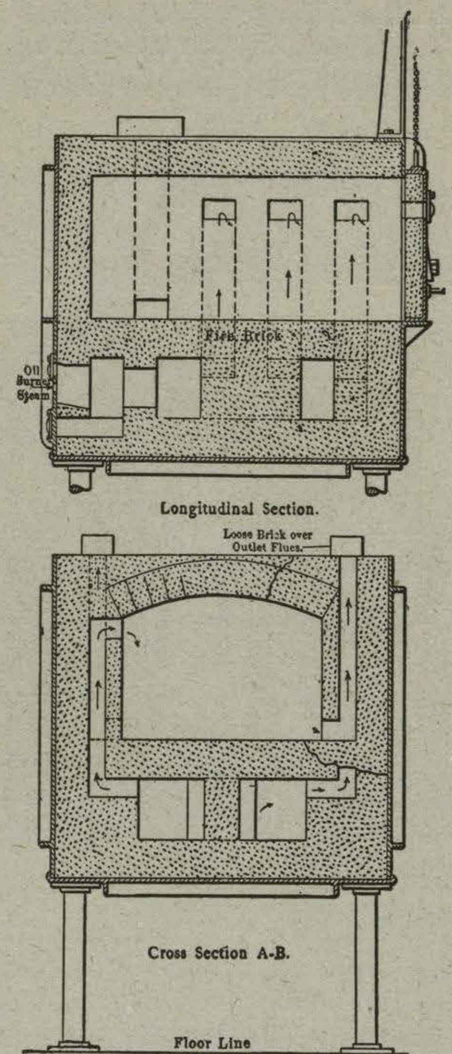

FIG. 83. — Details of under-fired furnace.

In the under-fired furnace, as shown in Figs. 83 and 84, atomized gas is injected into an opening underneath the heating chamber, and there the combustion takes place. It then passes through flues into the top of the heating chamber, and out of here through openings near the floor

into flues on the opposite side. These conduct it out of the furnace. The burners and the flues on this, as well as the over-fired furnace, are staggered on opposite sides of all the larger furnaces, to make the heat uniform in all parts of the heating chamber.

The construction of this furnace is simpler, and hence its first cost is less than that of the over-fired type. It is also much easier to reline and repair when burned out. The fuel consumption, however, is slightly greater than in the over-fired type and a uniform heat in all parts of the

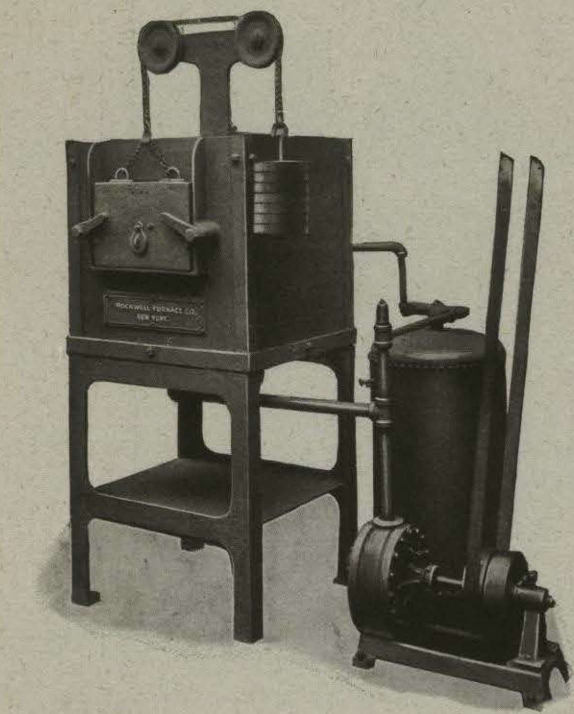

FIG. 84. — Small under-fired furnace with complete oil-burning outfit.

work chamber is not as easily obtained, especially in large furnaces. In the smaller under-fired furnaces the heat is easily controlled, and with oil fuel a high temperature can be attained and maintained throughout the day. This makes it very useful for tool hardening and tempering.

In Fig. 85 is shown an oil-burning furnace with a self-contained outfit that makes it portable, and Fig. 86 shows one with a water-cooled front. The latter is made of fire-brick, with any size or shape of openings desired, and is very useful for heating the ends of tools and keeping the bar cool enough to handle. In both of these furnaces a temperature of 2500° F. can easily be maintained, and thus any kind of high-speed steel can be hardened.

Another style of oil furnace is the muffle furnace. In this the gases surround the heating chamber, but do not enter it. Thus the metal is protected from any injurious effects from the gases of combustion while they are being heated.

Any of the above liquid fuel furnaces can be used for the gaseous fuels by merely changing the burners.

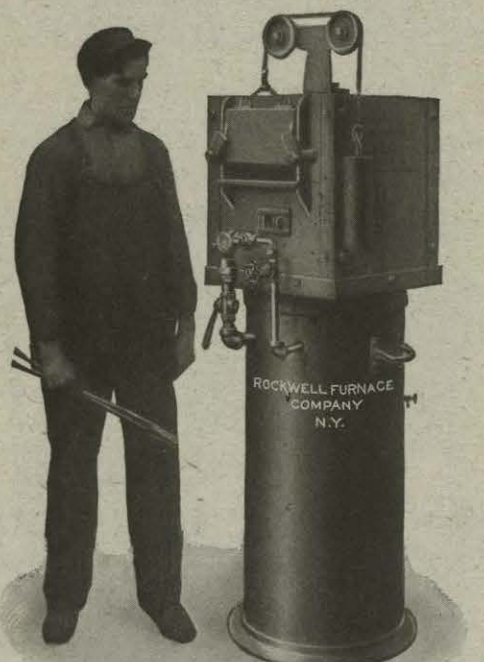

Fig. 85. — Portable oil furnace with self-contained outfit.

GASEOUS FUEL

Furnaces using gaseous fuel are growing in favor, and are constructed so they can use either natural gas, artificial gas, or producer gas. They are very easy to regulate, and if well built are capable of maintaining a constant temperature within a wide range. Their first cost is greater than that of solid fuel furnaces. The cost of installation, however, is soon paid for where natural gas, or possibly producer gas, is used for fuel, as then it is the cheapest furnace to operate. Artificial or city gas is more expensive than oil for fuel, but is much cleaner and easier to operate, as it is not necessary to install tanks or apparatus in which to store the supply. If the cost of the upkeep of these be figured in, there might not be such a great difference in the cost of furnace fuel, providing the city gas be

obtained at a reasonable price. Where high-grade steels are used, and the best work is demanded, doubtless gas is the best fuel.

Producer gas is continually increasing in use for furnaces, but unless a number of furnaces are operated, or a few large ones, a separate producer plant to supply the furnaces is not economical. Where a producer plant can be utilized for other things, such as furnishing power, it is probably a very cheap fuel to pipe from the central power plant and burn in the furnaces. With this, or any of the gas fuels, a large part of the heat that goes up the chimney, when other fuels are used, can be utilized in heating the air of combustion that enters the furnace. This can be done with very little special construction.

Fig. 86. — Oil furnace with water-jacketed front.

Results which are very uniform are obtained with the gas furnaces, and it is much easier to maintain a constant temperature for liquid baths than in a solid fuel furnace, or a metal retort may be used to place the work in for the purpose of keeping it away from the gases of combustion, with a greater assurance that the work in it will be raised to the proper temperature and maintained evenly for a given length of time.

One of the muffle or oven style of furnaces that uses gas for fuel is shown in Fig. 87. In this the blast connects at C with the end of the drum D, and goes through the pipe A, where it picks up the gas at G and carries it to the burners B. In placing a cutter like X, in the furnace, it should be supported by a fire-brick similar to Y, so the teeth will not touch the bottom slab Z. The door E has a counterweight above H, so it can be opened and closed quickly, and it slides in the guides *S*. At *P* is a peep-hole, and at *V* is a vent to allow the gases to escape from the furnace. This principle has been carried farther by revolving the oven,

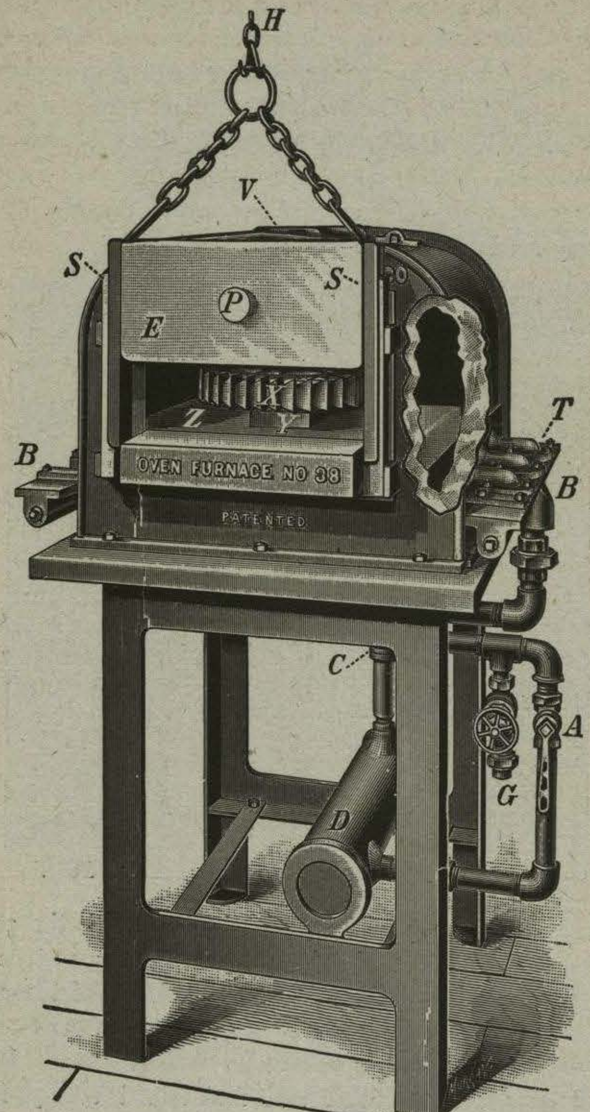

Fig. 87. — Gas furnace with oven.

or work holder, and sending the heating gases around it, as shown in Fig. 88.

Pyrometers can be used very easily to measure the heat with this style of furnace. Thus definite results may be obtained in the degree of temperature without depending on the skill or knowledge of the work-

man to as great an extent as with the furnaces using coal, coke, or charcoal for fuel. Furnaces using liquid and gaseous fuels differ very little in their construction, and are made in many different styles and sizes to suit the various materials they are to handle, or the kind of heat-treatment.

An instance of this is shown by the upright furnace in Fig. 89, which is for heating long bars or steel pieces. The heat is evenly distributed in the heating chamber by regulating burners *F*, which enter the furnace from four sides and on a tangent, so as to give the flames a swirling motion. They are controlled by the gas and air valves, *A* and *G*. For short lengths the upper burners *E* are shut off, and the section *Y* can be removed and

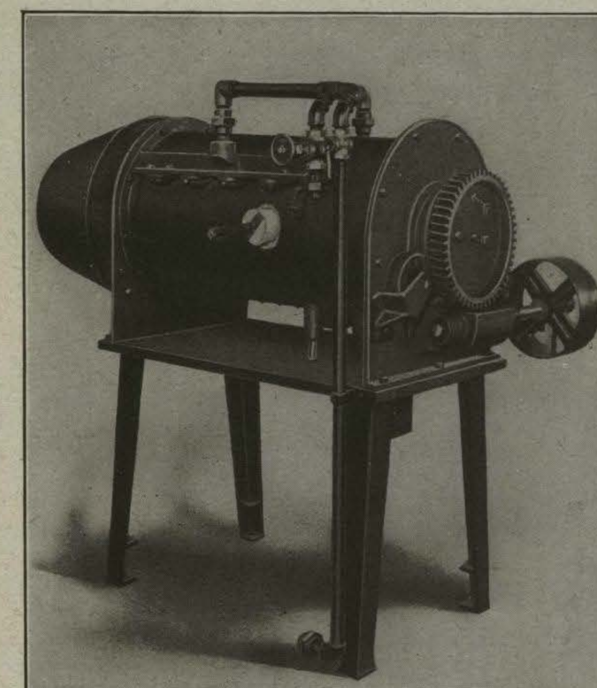

Fig. 88. — Gas furnace with revolving retort.

cover *Z* lowered. The large opening at *I* will give the necessary draft, and vents *H* can be used for peep-holes, while vent *P* allows the used gases to escape.

Special designs of furnaces have been made for all of the various operations of heat-treating, such as annealing, tempering, hardening, coloring, etc. Some of these have been made continuous operating and automatic as shown in Figs. 90 to 93 inclusive. In Figs. 90 and 91 is shown the furnace combined with a quenching bath, into which the work drops directly from the furnace. This quenching tank contains an automatic conveyer that lifts the work out of the tank and dumps it into a wheelbarrow shown in Fig. 91. Fig. 91 shows the details of the furnace as supplied with a smooth lining, and Fig. 92 shows the helical or worm lining that can be used with the same furnace if desired. The furnace is mounted in such a manner that its axis may be tilted at an angle, giving the revolving hearth an incline, with the discharge end lower than the entrance or feed end. The gradual incline causes the material to feed forward, and by means of a hand-wheel the degree of pitch may be adjusted so as to regu-

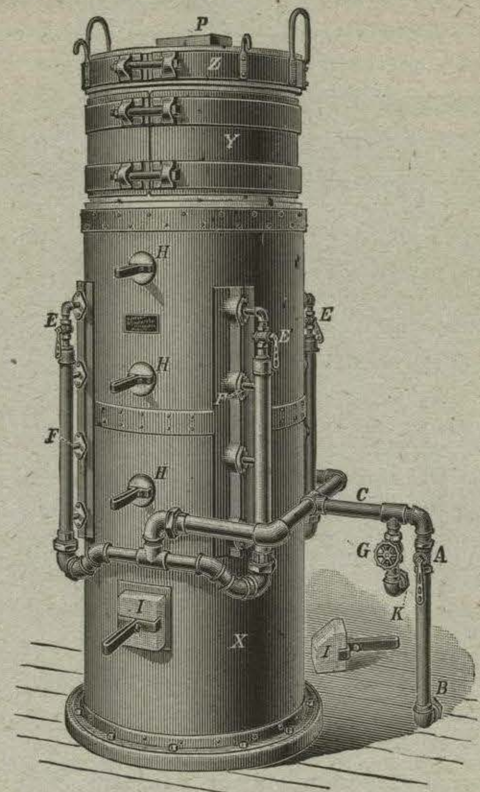

FIG. 89. — Upright gas furnace.

late the progression of the material through the furnace, and consequently the time of heating.

The advantages of this method of automatic continuous heating are many: The material is charged in a hopper in bulk at one end of the furnace and fed automatically into the chamber. It comes continually in contact with the newly heated interior surface, which is revolving, thereby absorbing the heat from the lining as well as from the heated gases. In a stationary furnace the heat from the sides and roof are not utilized, as the material remains in a fixed position; that farthest removed from the heat requires a much longer period to be brought to the desired

temperature and the more exposed pieces are liable to overheating, while others are insufficiently heated. To prevent oxidation, the end of the

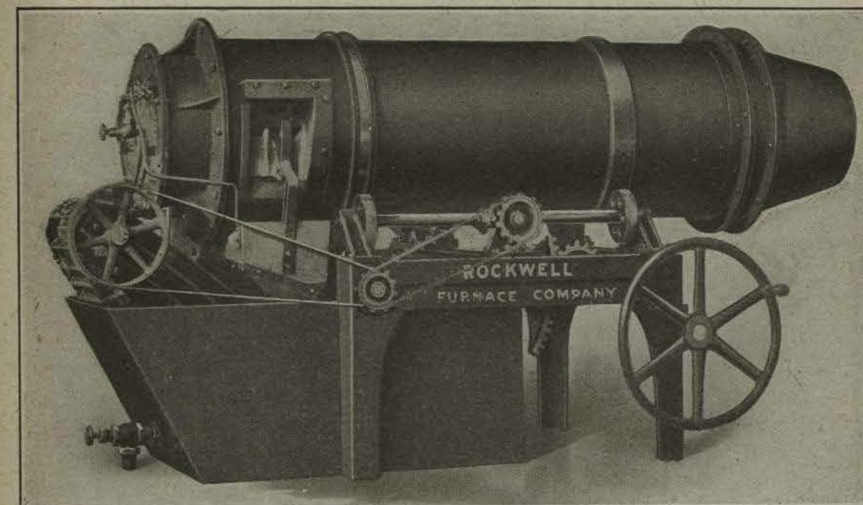

FIG. 90. — Automatic and continuous hardening furnace, with tilting mechanism.

discharge spout may be carried beneath the level of the bath, thereby sealing it and excluding the air.

In operation, the pieces are fed continuously into one end of the cylin-

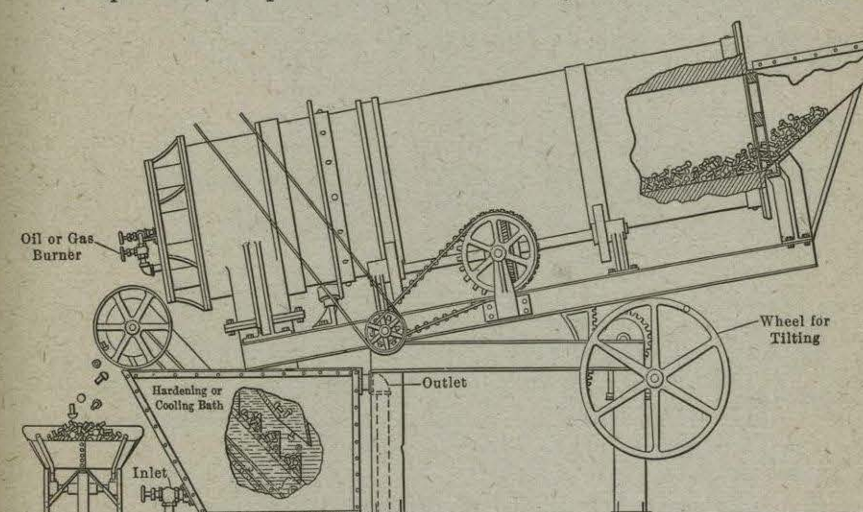

FIG. 91. — Details of continous hardening furnace, showing smooth interior.

der. The furnace is fired internally from the opposite end, with the zone of highest temperature at the discharge end. The cylinder revolves slowly (1 to 4 revolutions per minute), and owing to the slight inclina-