DESPITE the growth of alloy steels and special means of surface hardening, the ancient art of carburizing steel remains one of the fundamental operations in the manufacture of machine parts. It retains its popularity because it enables the workman to start with a material that can be easily machined, and end with an excessively hard and desirable surface for resisting wear, retaining ductile metal underneath with sufficient strength and shock-resisting properties to stand up to severe duty.

As is well known, most carburizing is done by the time-honored method of packing the steel with carbonaceous materials in suitable containers, covering it in such a way as to prevent infiltration of furnace gases, then raising the temperature to a suitably high point, and holding it there for some hours, depending upon the depth and character of case desired. Carburizing by this means is dependent on a number of factors, many of which arise from the character and uniformity of the compound; great care must therefore be used in handling the compound to obtain satisfactory results. At best, there are still many variables that are hard to control and results that are difficult to explain.

It has been felt for many years that this metallurgical process is too cumbersome and dirty to fit in well with modern manufacturing practice. To those who have studied the matter, it seemed that the desired improvement could be had in a process for carburizing with an externally prepared gaseous atmosphere. Such an atmosphere could be clean, of uniform composition, easily controlled, always fresh and theoretically desirable.

As a matter of fact, a great deal of work has been done on these lines; many valuable contributions have been made that have resulted in installations of considerable commercial importance. The complexity of the possible chemical reactions involved has brought about the ingenious application of mechanical equipment for the control of atmosphere. This is one characteristic of gas carburizing today.

Attention, until now, seems to have been centered upon the development of a series of intermittent or recurring operations whereby the treatment of one lot of steel parts is completed before the work on the next one begins.
This is satisfactory for many purposes, and its successful development was a distinct step forward. However, the trend in mass production is along the line of continuous movement of materials through a factory; hence it seemed necessary that attention should be given to the development of a process that would fit in with these requirements.

After considerable research work and study in the laboratory of Surface Combustion Corp., such a process has been worked out that has many interesting and attractive features. It is interesting, not only from the theoretical and scientific standpoints, but also because it lends itself so well to modern shop conditions.

A discussion of the gas reactions and other theoretical considerations has been given by the author to the American Institute of Mining & Metallurgical Engineers at the recent Boston meeting of the National Metal Congress (Technical Publication No. 439). The present article will consider the industrial applications, and will present some of the results that have been obtained by repeated tests, mentioning the chemistry of the process briefly in passing.

Essential details of the continuous gas carburizing process may be summarized briefly as follows:

A hydrocarbon gas, such as methane, ethane, propane or butane, is mixed with the products of combustion of a gas-fired furnace, the latter containing from 8 to 10% of carbon dioxide. These mixed gases are dried and introduced into a muffle containing work to be carburized, in such a manner that they will flow through the muffle in the same direction as the work. Rapid diffusion is prevented by suitable baffles throughout the muffle. The work is then moved progressively through three successive reaction zones of the furnace. In the first or preheat zone the hydrocarbon gas begins to break down into its constituents, hydrogen and carbon, the exact temperature depending on the hydrocarbon used, but in any event is below 1450° F., so that the work to be carburized soon becomes covered with a deposit of carbon. Carbon deposits on the surface of steel to be carburized rather than on the walls of the muffle.
through which it is passed, or the work carriers, since these are made of a certain class of heat-resisting alloys which will not catalyze the gas decomposition to any great extent. The presence of flue gas in this first zone of the furnace serves only as a desirable diluent for the rich carburizing gas.

**Methane Counteracts Hydrogen**

As the work, now covered with carbon, moves along through the furnace it comes into the high temperature or carburization zone at approximately 1650° F., in which the carbon dioxide of the flue gas becomes active. In this zone the carbon dioxide reacts with carbon to form carbon monoxide, in accordance with the reversible chemical reaction \( \text{C} + \text{CO}_2 \rightleftharpoons 2\text{CO} \). This means that carbon monoxide, which is known to be an active carburizing gas, is being formed progressively by carbon directly in contact with the metal surface to be carburized. It is important to note that in this middle zone there is always present, along with the carbon and its oxides and hydrogen, a certain amount of hydrocarbon gas that has not broken down completely (or at least there remains considerable methane, \( \text{CH}_4 \), which is the last stage of its decomposition). The presence of this hydrocarbon prevents the decarburization of the metal in the atmosphere, high in hydrogen, that surrounds it in this zone.

After spending the required time in passing through this high-temperature carburizing zone, the work enters the third, or diffusion zone, held at the same temperature. Here, also, there is a simple adjustment between methane and hydrogen and between carbon monoxide and carbon dioxide to produce an “inert” atmosphere, that is to say, one which prevents any decarburization of the exposed steel surfaces. By holding the metal in such an atmosphere, there is brought about a progressive diffusion of carbide from the case inward to the core, so necessary for a satisfactory adherent case.

Apparatus simple in operation and rugged in construction has also been developed. Its general design is shown in the accompanying drawing. It consists of a muffle chamber extending throughout the furnace length, ending at the charging end in a purging chamber, and at the discharging end in a cooling chamber. This discharge chamber can be arranged so it may be held at temperature, prior to quenching the freshly carburized parts without an intermediate reheating. Both of these small chambers are separated from the main body of the muffle by gate valves which make the muffle gas-tight. Doors at opposite ends, leading to the outside, have a machined edge which is held tightly against the slides by a cam or toggle.

Work is carried through on alloy grids or trays of sufficient rigidity to carry the load. The grids ride through the muffle on rails and rollers.
the movement being actuated by a suitable pusher. The mixture of carburizing gases is introduced continuously at the correct rate at the charging end of the muffle, both above and below the work, so as to flow concurrent with the work throughout the entire length of the muffle. Spent gases burn at the discharge end.

This furnace is heated by gas burners firing above and below the muffle. Temperature is controlled by automatic regulators and thermocouples placed at three different points in the muffle. A unit of this type will occupy about 60% of the floor space required by a pack furnace of equivalent tonnage.

**Furnace Operation**

Operation is as follows: A loaded grid is placed in the chamber at the charging end of the furnace. After the outside door is closed this chamber is purged; that is, the air is replaced with flue gas. When the inner doors or valves at both ends of the muffle are raised simultaneously, the pusher shoves the load into the furnace, and (assuming that the muffle has been filled) a corresponding load is pushed out into the cooling or holding chamber. After lowering the inner doors the finished load may be removed when it has cooled sufficiently, or it may be held at the quenching temperature.

Comparing this process with the usual practice of pack carburizing, the following advantages will be observed:

(a) Lower first cost of unit,
(b) No compound handling systems,
(c) Less labor for loading,
(d) Elimination of expensive containers,
(e) Where direct quenching is required, a definite holding zone is provided, thus eliminating labor for reheating operations,
(f) Fuel saving due to reduction of gross materials being heated.

We believe that for the first time in the history of carburizing, this process offers to industry a method of controlling the type of case to be produced on the surface of the steel. This control is exercised by regulating the proportion of hydrocarbon gas and flue gas used for the carburizing mixture. Changes in the relative amount of these two gases are reflected directly in the type of case produced, whether a low carbon hypo-eutectoid case, a higher carbon eutectoid case, or a hyper-eutectoid case with still higher carbon.

We withdraw from the outlet end of the muffle a small amount of gas for analysis that has passed through the carburizing reactions. By means of a special method of analysis for carbon dioxide and methane, made with automatic and recording equipment, the operator knows at all times what the exact carburizing conditions are within the furnace proper, and is able to detect at once any changes that may have taken place due to mechanical difficulties or other causes. This chart is similar to the well-known pyrometer record. Such a record of carburizing conditions taken continuously from the carburizing chamber reveals what is going on and offers a means of control never before realized.

It has therefore been possible to produce

Hyper-eutectoid Case About 0.040 In. Deep in S.A.E. 1020 Steel Made in Production by Continuous Gas Carburizing Furnace. Note gradual transition, zone to zone.

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Hyper-eutectoid Case About 0.040 In. Deep in S.A.E. 1020 Steel Made in Production by Continuous Gas Carburizing Furnace. Note gradual transition, zone to zone.
finished parts of very fine uniformity, not only within the piece itself, but from piece to piece throughout an extended run. This is illustrated by three micrographs of typical cases produced during a long test on this furnace. Each one of each lot was so nearly like its fellows as to be almost indistinguishable, the only difference noted in depth of case being due to fine grain in the steel, but only amounting to 0.002 in. even from this cause.

**Penetration is Rapid**

Rate of carburizing is high. We found that a case penetration of 0.045 in. could be obtained in 3 hr. at a temperature of 1675° F. with S.A.E. 2315 steel (about three times the usual carburizing rate of pack carburizing).

Diffusion between case and core has been found to be uniform and gradual, regardless of the amount of carbon in the case, indicating that there is a good bond between the two. The usual sharp line of demarcation, so common where carbon monoxide alone has been used as the carburizing agent, is absent.

Attention must be called also to the fact that the process is clean. By proper regulation of the ratios of the carburizing gases, it is possible to bring the work from the furnace without any free carbon on it, clean and in condition for the next operation. There is no packing of boxes, nor handling of hot, dusty compound, since the carburizing medium is wholly gaseous.

This contribution to the science of carburizing is making a strong appeal to the industry, and one large commercial installation is in operation at the Newcastle plant of Chrysler Corp., and others are under construction. It is hoped that it will prove to be of real assistance in the scientific heat treatment of steel.

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*Samples Taken at Random From Production of Automotive Parts of S.A.E. 1020 Steel. Case desired: 0.060 in. Compare uniformity, piece to piece, and also compare structure of same part shown on page 47, when controls had been adjusted for somewhat shallower case.*