

## Introduction to Carburizing and Carbonitriding

### Methods of Carburizing and Carbonitriding

[Table 5](#) summarizes the advantages and disadvantages of different carburizing methods. Each method is described in more detail in separate articles of this Volume. The related process of carbonitriding is also briefly compared in this section with more details in the article [“Carbonitriding of Steels”](#) in this Volume.

**Table 5 Advantages and disadvantages of carburizing methods**

Advantages	Disadvantages
<b>Pack carburizing</b>	
Low capital requirements	Labor-intensive
No atmosphere generation required	Control of case depth and carbon is difficult.
	Direct quenching is impractical.
	Energy- and time-intensive due to the necessity of heating the additional mass of the container
	Some pack compounds (such as barium carbonate) are hazardous.
	Process is very dirty and requires that parts been cleaned before hardening.
<b>Liquid carburizing</b>	
Rapid heatup can produce case equivalent to other methods in less time.	Molten salts present safety and environmental challenges.
Selective carburization is possible by immersing only a portion of the component in the salt.	Salt residue can contaminate downstream processes.
	Not easily adapted to high-volume or continuous operation
<b>Gas carburizing</b>	
Easily scaled to large-volume production and continuous operation	Significant capital equipment costs
Atmosphere is easily instrumented and controlled.	Safety and environmental issues surrounding the use and exhaust of atmosphere gases and products of combustion
Parts can either be direct-quenched or rehardened in a separate operation.	Surface intergranular oxidation can be controlled but is unavoidable.
<b>Low-pressure (vacuum) carburizing</b>	
Intergranular oxidation eliminated	Capital equipment costs typically highest of all methods
Reduced energy consumption when compared to gas carburizing. No generators required; power used only when running a load	Not easily adapted to high-volume or continuous operation
Low environmental impact	Difficult to exactly duplicate microstructure from conventional liquid quench processes with high-pressure gas quench due to limited cooling rates available
Parts are very clean after processing.	

**Pack carburizing** is the original carburizing technique, and therefore, it dates back several thousand years. It has been replaced by gas and vacuum carburizing and is no longer a commercially significant process. Although essentially obsolete, pack carburizing is still practiced by educational institutions and small tool shops that lack modern carburizing facilities.

Pack carburizing involves placing a component in a metal container, surrounding it with a suitable powdered carbonaceous material, sealing the container, heating it to the carburizing temperature range, and holding it there for a suitable period of time.

During pack carburizing, the carbonaceous material in the box decomposes, filling the box with carbon monoxide. At this point, pack carburizing actually behaves much like gas carburizing. Over the years, various carbon sources have been used. Biological sources have been used from the beginning and remain in use to some extent today (2013). Examples of materials used for pack carburizing are crushed animal bones, charred leather, charcoal, or coke. Modern pack carburizing compounds are typically based on charcoal or coke with the addition of various alkaline metal carbonates that serve as activators or catalysts.

The box is a crucial piece of equipment. It serves as the container or furnace that holds the atmosphere created by the reactions of the compound. Ideally, a box should be as small and light as possible to minimize the amount of time and energy required to heat the entire assembly. The box may be fabricated out of a variety of materials ranging from plain carbon steel to stainless steel or high-temperature alloys. Materials selection will be driven by the size of the box and if it is intended to be reused.

The mass and cross section of a pack carburizing box make quenching directly from carburizing impractical, so pack-carburized components must be hardened and quenched in a separate operation.

**Liquid Carburizing or Salt Bath Carburizing.** Traditional liquid carburizing, also known as salt bath carburizing, involves the carburization of a component by immersion into a molten salt bath containing cyanides. This should not be confused with a relatively new process known as liquid induction carburizing, which is discussed later in this section.

Liquid carburizing is a process that has been largely replaced by gas and vacuum carburizing. Although it is still used by some shops that have access to legacy equipment, it is commercially obsolete.

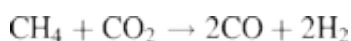
Traditional liquid carburizing involves heating of the component in a bath of liquid salts containing cyanide. The liquid salt provides an efficient medium for heat conduction into the component, and the cyanide provides the carbon for diffusion.

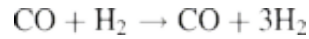
In traditional liquid carburizing, components are carburized in a salt bath by lowering them into the molten salt by means of a hoist or other lifting device. This method of charging parts provides a unique opportunity: Parts can be preferentially carburized by selecting how much of the component is immersed into the salt. Other masking or stopoff methods may be used, but compatibility of the stopoff with the salt must be determined before use.

Liquid induction carburizing is a relatively new, nontraditional carburizing method. Unlike the molten salt bath used in traditional liquid carburizing, liquid induction carburizing uses a room-temperature liquid hydrocarbon bath. The component is heated to carburizing temperatures by an induction coil while immersed in the liquid hydrocarbon. Carburization occurs as the liquid hydrocarbon dissociates on the surface of the heated component. In addition to acting as a carbon source, the liquid hydrocarbon bath also serves as a quenchant and protects the component from oxidation. The configuration of the liquid induction carburizing process permits the component to be carburized, hardened, and tempered in the same fixture. Because part heating is not constrained by the limitations of a traditional furnace, liquid induction carburizing can make use of high carburizing temperatures (approximately 1200 to 1250 °C, or 2190 to 2280 °F), resulting in relatively short processing times. This ability also presents the intriguing possibility of expanding the scope of carburization to materials other than steel. Liquid induction carburizing has been used to develop carbide cases with significant thickness on various refractory metals, such as titanium, vanadium, chromium, zirconium, niobium, molybdenum, tantalum, and tungsten. While still experimental in nature, liquid induction carburizing has found limited use in medical and aerospace applications.

**Gas carburizing** is the most commercially significant carburizing technique. The distinguishing characteristic of gas carburizing is the technique of enveloping the workpiece in a gaseous atmosphere that is generated from hydrocarbons such as methane, propane, butane, or methanol.

In considering the case of natural gas (methane), the key reactions would be:





The atmosphere is typically delivered by a carrier gas into which a sufficient amount of the hydrocarbon gas is added to produce the desired carbon potential. The most common carrier gas is known as endothermic gas. It is produced by passing the hydrocarbon over a nickel catalyst at temperatures of 980 to 1000 °C (1800 to 1830 °F). The most common hydrocarbon used to produce endothermic gas is natural gas or methane (CH<sub>4</sub>). The composition of a typical methane-based endothermic gas is approximately 40% H<sub>2</sub>, 40% N<sub>2</sub>, and 20% CO, with small amounts of water vapor, CO<sub>2</sub>, and unreacted CH<sub>4</sub>. Endothermic gas must be handled with caution because it is both flammable, due to its H<sub>2</sub> content, and an inhalation hazard, due to its carbon monoxide (CO) content.

Endothermic gas serves as a protective atmosphere at elevated temperatures. Its H<sub>2</sub> and CO content will protect parts from scale and oxidation. However, its carbon potential is too low to carburize on its own. To create the required carbon potential, straight hydrocarbon is added to the endothermic atmosphere in the proper proportion to produce the desired result. This is known as enrichment.

Gas carburization usually takes place by first heating the load under cover of straight endothermic gas. The load is allowed to heat through and stabilize at the carburizing temperature while the endothermic gas protects it from oxidation (although some degree of intergranular oxidation is inevitable). Once the load has equalized at the desired temperature, carbon-potential control is activated and the enriching hydrocarbon is added to achieve the desired carbon potential. The load is held at temperature for a time sufficient to achieve the required case depth, at which point the enriching gas addition is stopped and the load is either cooled to an appropriate hardening temperature and quenched (direct quench) or allowed to cool to room temperature and then hardened in a separate operation (rehardening). Rehardening is sometimes used where a finer grain size is required after heat treatment.

There are two main approaches to the carburization step. One is known as single-stage carburization and the other is known as boost-diffuse. In single-stage carburization, the carbon content is held constant throughout the carburization step.

In boost-diffuse carburizing, the time for the carburizing step is divided into two phases. In the first stage, known as the boost phase, the carbon potential of the atmosphere is set nearly to saturation and held for a time sufficient to diffuse maximum carbon into the surface. In the second, or diffuse stage, the carbon potential is lowered to that of the desired final surface carbon, and the high carbon content at the surface is allowed to diffuse into the steel to produce the desired carbon and hardness profile. Boost-diffuse carburization has been demonstrated to produce an effective case depth equivalent to that of single-stage carburization in less time. The boost-diffuse process is best suited to batch furnaces, where the entire carburization step takes place in the same furnace chamber or zone.

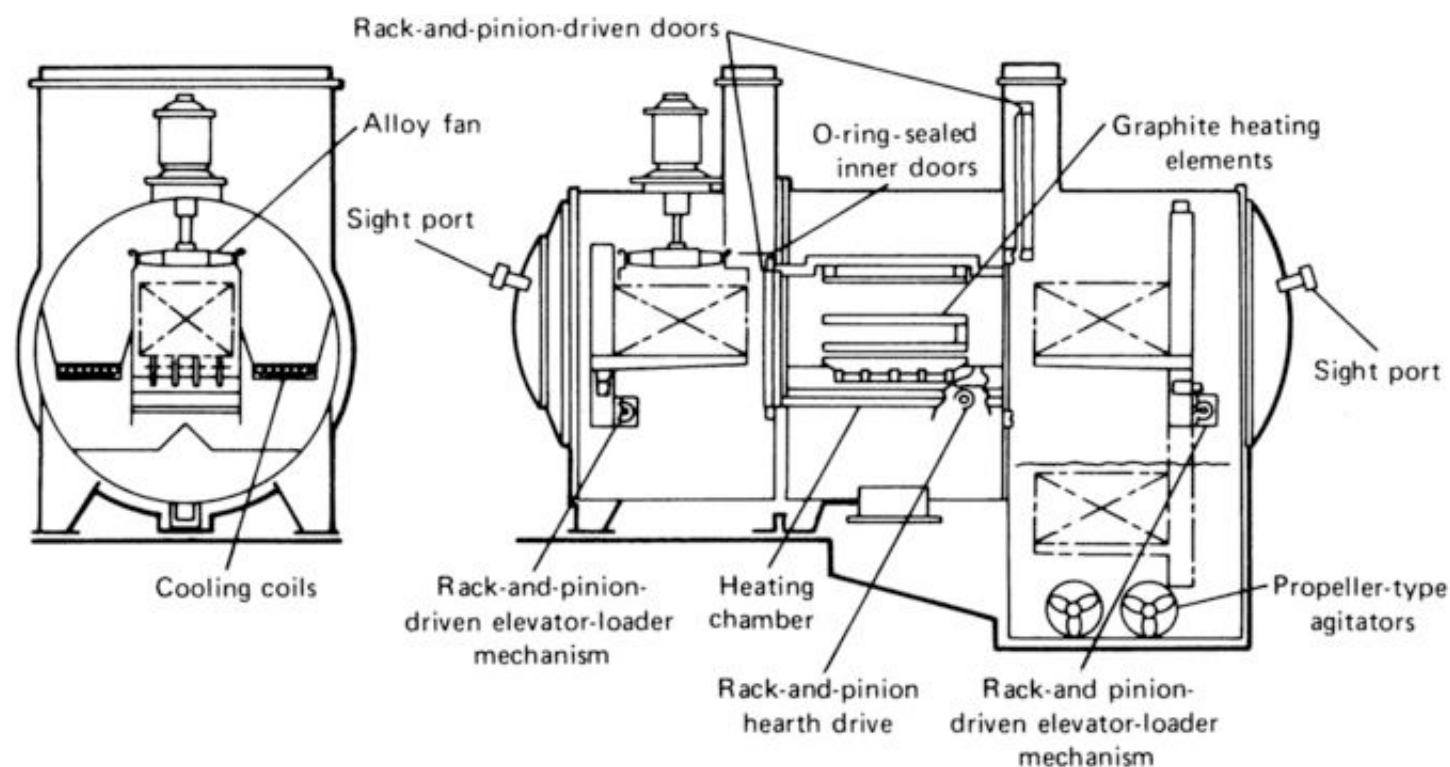
Gas carburizing is used in both batch and continuous processes. A wide variety of furnaces types, configurations, and sizes are in use around the world.

**Low-Pressure (Vacuum) Carburizing.** Vacuum carburizing, or more properly, low-pressure carburizing, is a far second to gas carburizing in terms of worldwide carburizing capacity, but it is growing in popularity and has some distinct advantages over gas carburizing that make it the preferred process for certain applications.

In vacuum carburizing, the vacuum is actually a very low-pressure atmosphere created by a vacuum pump. Carburizing is made possible by breaking the vacuum at the appropriate time in the cycle with a partial pressure of a hydrocarbon gas such as propane, acetylene, or some other suitable hydrocarbon blend. A carrier gas such as nitrogen is sometimes used to provide a neutral partial pressure in the chamber and to use the hydrocarbon. Carburization occurs in the vacuum furnace as the hydrocarbon gas comes into contact with the surface of the steel. Unlike gas carburizing, methane is rarely used in vacuum carburizing because it does not dissociate well at the ordinary carburization temperatures. Propane and acetylene are better choices for vacuum carburizing.

For carburization to take place, the surface of the component must be free of oxides. For this reason, it is important that the vacuum be established in the vessel before the temperature gets high enough to form oxides on the workpiece (approximately 550 °C, or 1020 °F). Maintaining a sufficient vacuum reduces the oxygen available to produce intergranular oxidation on the component, so intergranular oxidation can essentially be eliminated.

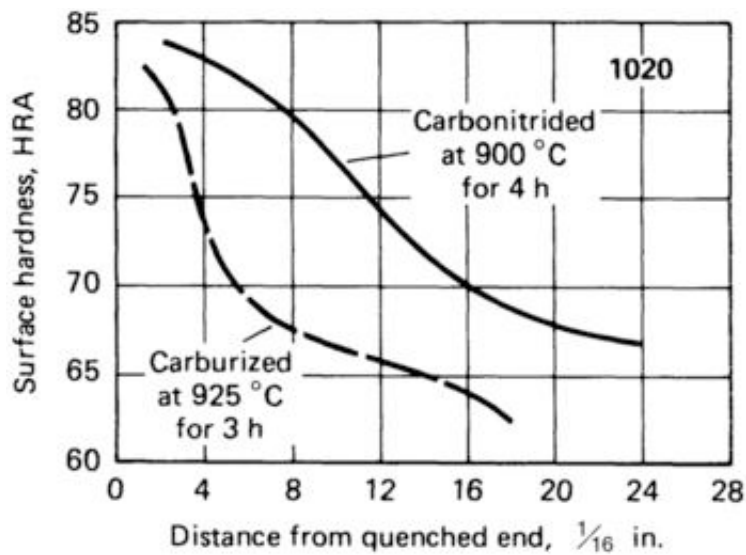
Many vacuum furnaces are designed to permit quenching of the load by the introduction of inert gas at relatively high pressures once carburization is complete. This makes it possible to carburize, harden, and even temper a load in the same chamber. This technique works best with lighter loads, thinner-section parts, and high-hardenability steels. There are applications where high-pressure gas quenching is unable to reproduce the exact microstructure obtained in a traditional liquid quench. If a particular microstructure is necessary that can only be produced with a faster quench rate, it may be necessary to harden the components in a separate operation or use a multichamber vacuum furnace, where it is possible to have a separate chamber dedicated to a liquid quench ([Fig. 24](#)).



**Fig. 24 Three-chamber vacuum furnace with an oil quench chamber**

**Carbonitriding.** As noted in the introduction of this article, carbonitriding is a modified form of carburizing rather than a form of nitriding. The modification consists of introducing ammonia into the gas carburizing atmosphere in order to add nitrogen to the carburized case. The ammonia in the atmosphere dissociates on the surface of the component, generating nascent nitrogen. The nitrogen then diffuses into the steel simultaneously with the carbon. Steels with carbon contents up to 0.2 wt% are commonly carbonitrided. Typically, carbonitriding takes place at lower temperatures and shorter times than gas carburizing, producing a shallower case—typically from 0.075 to 0.75 mm (0.003 to 0.030 in.) deep.

Carbonitriding differs from carburizing and nitriding in that carburized cases normally do not contain significant nitrogen, and nitrided cases consist primarily of nitrogen, whereas carbonitrided cases contain both. One major advantage of carbonitriding is that the nitrogen absorbed during processing lowers the critical cooling rate of the steel. Thus, the hardenability of the case is significantly greater when nitrogen is added by carbonitriding than when the same steel is carburized. Carbonitriding also increases the case hardness ([Fig. 25](#)). Full hardness with less distortion can be achieved with oil quenching, or, in some instances, gas quenching is possible by using a protective atmosphere as the quenching medium.



**Fig. 25 End-quench hardenability curve for 1020 steel carbonitrided at 900 °C (1650 °F) compared with curve for the same steel carburized at 925 °C (1700 °F). Hardness was measured along the surface of the as-quenched hardenability specimen. Ammonia and methane contents of the inlet carbonitriding atmosphere were 5%; balance was carrier gas.**

Often, carburizing and carbonitriding are used together to achieve much deeper case depths and better engineering performance than could be obtained by using only the carbonitriding process. The process generally consists of carburizing at 900 to 955 °C (1650 to 1750 °F) to give the desired total case depth (up to 2.5 mm, or 0.10 in.), followed by carbonitriding for 2 to 6 h in the temperature range of 815 to 900 °C (1500 to 1650 °F) to add the additional carbonitrided case. The parts can then be oil quenched to obtain a deeper effective case depth and thus a harder case than would have resulted from the carburizing process alone. The addition of the carbonitrided surface increases the case residual compressive stress level and thus improves contact fatigue resistance, as well as increases the case strength gradient. When the carburizing/carbonitriding processes are used together, the effective case depth at 50 HRC to total case depth ratio may vary from approximately 9 to 19 mm (0.35 to 0.75 in.), depending on the case hardenability, core hardenability, section size, and quenchant used.