LOW-PRESSURE CARBURIZING (LPC) FOR HARDENING LARGE GEARS IS A NEW APPROACH TO TRADITIONAL TECHNOLOGY. ALLOWS YOU TO WORK AT HIGH TEMPERATURES (980-1040°C) DRASTICALLY REDUCING CARBURIZING TIMES

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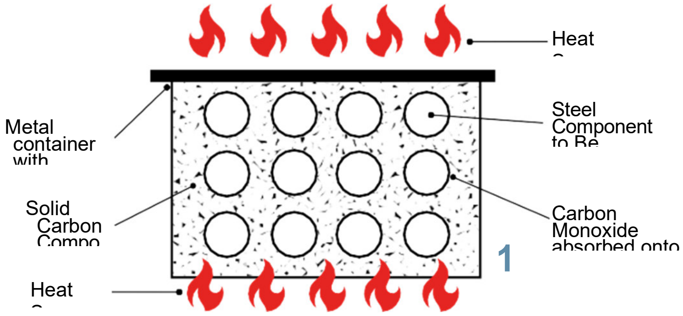
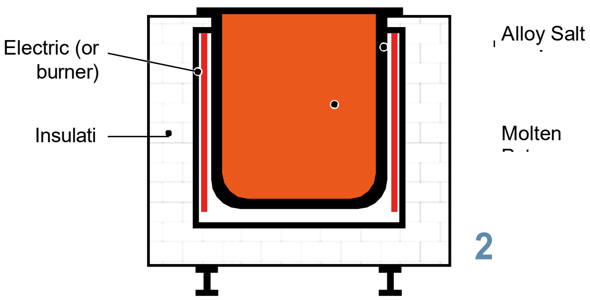
A NEW SOLUTION

FOR LOW PRESSURE CARBURIZING

I Cementation Treatment, a Method of Surface hardening steels, is reaching its centenarian. Although carburizing in carbon-rich environments (gas carburizing) was practiced even before the 20th century, the "modern" Cementation Process can be traced back to the beginning in The 1920s. Now, after 100 years, several methods are available to make carbon penetrate ferrous metal surfaces.





Figures 1. Solid cementation: example
Figures 2. Example of liquid carburizing furnace (salt bath)

Surface Carbon by Diffusion is the basis of the increase in surface hardness. Austenitization is a phase Transformation of Steel that occurs at Temperatures above 1340 °F [725 °C] and absorbs higher levels of carbon. Methods that take advantage of austenitization Includes:

- solid cementation ;
- liquid cementation (salt bath);
- gaseous cementation;
- Low pressure carburizing [LPC]

All these methods induce a transformation of thesurface making it resistant to wear while leaving a Soft and resistant heart. Cementation is usually done through the use of furnaces having various designs, shapes and sizes. The most modern heat treatment furnaces Can work continuously, semi-continuously and batch and can work in horizontal, vertical or rotating configuration. Production Volumes, Component Geometry, material quality , variety of geometries and Material types influence the optimal type and Configuration of the Oven. The grade of the Material and cross-sections Can drastically affect the design based on the hardening intensity required to achieve the desired hardness.

Since carburizing is carried out On low-carbon materials , the cooling Process Must Be rapid to prevent the transformation of the core from austenite into ferrite/ perlite. Higher grade cabonium steels generally do not require an aggressive cooling Process and slower hardening average can be used. Carburizing depths vary drastically depending on component size and process parameters. The required carburizing depth directly affects the service life required for a given level of increase in carbon on the Surface. The deeper the desired cementation depth, the longer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Figures 3. Box oven (integral hardening), Source of Electric heat (or burners), Molten Salt Bath
Figures 4. Well furnace
Figures 5. Continuous oven

It will be the diffusion phase. When High depths are required, significant Process Times are required at very high temperatures of 1700°F [925 C]. For example, a depth of 0.08" [20 mm] takes about 12 hours, and 0.15" [3.8 mm], about 36 hours. When cementing at Lower temperatures, the Diffusion of the Carbon occurs much slower and Can take Up to Twice As Long . In general, whenSmall Volumes of work and Low masses are required , horizontal furnaces are used.

With large components and weight, configuration becomes the preferred method for heat treatment. Since these large components tend to be quite heavy, Material handling requires an Overhead Crane . It is also worth noting how comparing the working volume of a horizontal furnace with a pit furnace, the Well furnace will be less expensive to Produces in addition to Having the Ability to Manage a Greater Mass Per Volume of work. The Fireboxes of the well furnaces Can Handle much Greater masses since they are loaded by an Overhead Crane System. When production requires carburizing On large components, the Best Furnace Configuration | will be Well. Long components typically require a system support during heat Treatment in order to avoid Sagging and Deformation under its own weight. Long components Can Be large and bulky (with small volume loads) or small diameter (with large volume loads). It is common that large components require High carburizing depths, this Means that the components will have to remain in the furnace for Long periods while maintaining the furnace busy and not able to deal with additional components. Whereas high depths on large components keep busy the furnace for Long periods, Manufacturers are pushed to heat treat as many components as possible in the same Oven. Furnaces will have to handle ever greater loads.

Cementation Methods

Solid Cementation

Solid cementation is one of the most common forms of cementation. Carbon is added to to steel Component by decomposing a Solid Compound within a Space As shown in Figure 1.

Solida carburizing is characterized by higher temperatures than to those of gaseous and liquid cementation. The process is very challenging to control, it produces non-repeatable results, requires a Core Treatment Process (two to large Grains and slow cooling) and a subsequent process for surface treatment. Therefore, Solid Cementation is not commonly used at all.

because of its Manpower lack of Process Control and problems environmental, leaving room for Alternative cementation Methods.

Liquid Cementation

In liquid carburizing, Steel components are immersed in a bath of molten salts and kept at temperatures above the transformation andAustenitic range. The bathroom Salts consist of sodium Cyanid (the Source of carbon), barium chloride and sodium chloride. The Decomposition of these salts at High Temperatures Causes Carbon to Be released close to the Surface of the austenized Steel and that en spreads Inside The steel. Also notes how nitrogen can sometimes spread to the surface. Heating of the Salt Bath reaches temperatures in the range of 1560-1650 °F [850-900 °C] for Shallow Cementing and 1650-1750 °F [900-950

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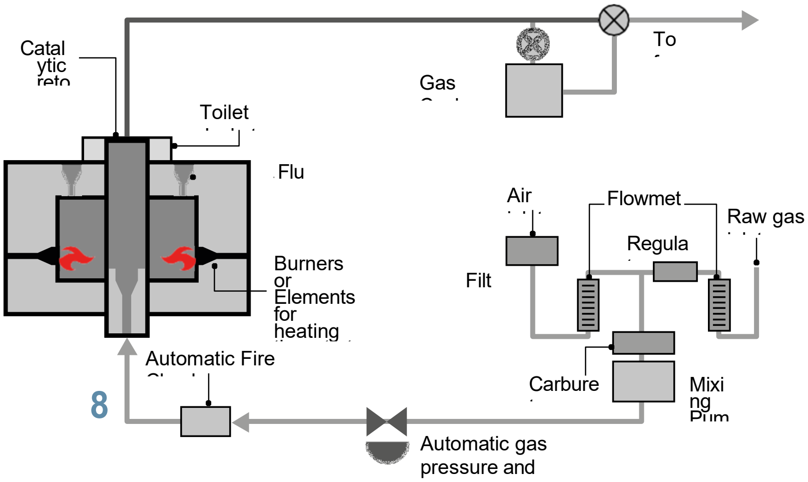

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Figures 6. Rotary oven
Figures 7. Endothermic gas generator
Figures 8. Schematic arrangement of generator pipes endothermic gas [4]
Figures 9. Vacuum furnace
Figures 10. Oil quenching furnace [7]

Salt baths provide excellent temperature control, Rapid heat Transfer and allow direct quenching after cementation. Figures 2 Shows a typical Configuration of an electrically heated Salt Bath Oven. Cementation in a salt bath, like solid cementation, does not appear to be a method Cementation commonly applied at industrial level two to the problems related to the salt bath. At higher temperatures,

The degradation of the Salt Bath and Furnace Components | takes place at accelerated speeds which require a Massive Supply of salts and constant maintenance of the furnace. Two to the Decomposition of Salt a "mud" is formed that requires constant removal and recharging of the saline composition. After quenching and two to the residual salts that join to the Component washing is necessary.

Therefore, Liquid Cementation is not Recommended for components that have complex geometric characteristics such as threads, cracks and/or Small Holes. In addition, the residual Salt remaining on

Gas carburizing

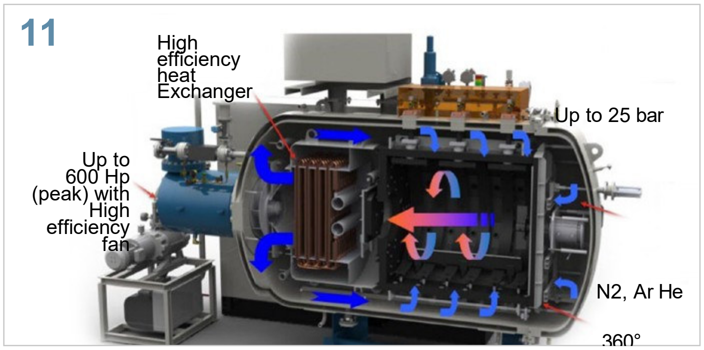
Gas carburizing, developed since 1950, has become the preferred technique because of the uncertain nature of the results of solid cementation and the problems Associatedwith Liquid Cementation. Currently gas carburizing is the most widely used type of carburizing in industry. For that

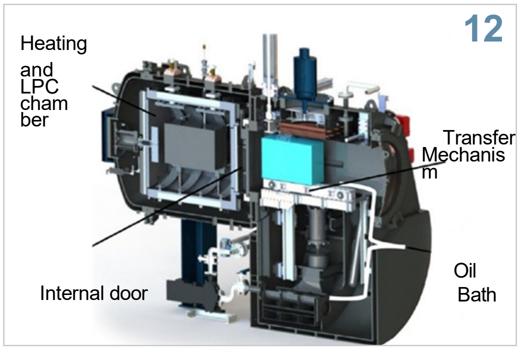
A wide variety of conventional furnaces are used, including Well, playpen continuous and rotary furnaces, for

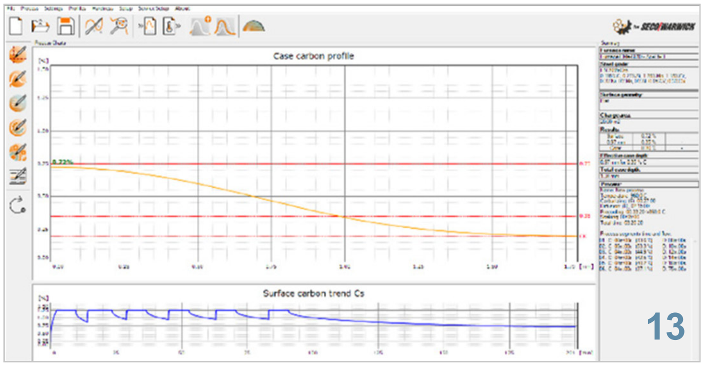
gas carburizing and, As in any heat treatment process, the correct choice of furnace design largely depends on the geometry of the components, production and production flow. Figures 3 to

6 show the types of atmosphere furnaces equipped for cementation. In gas carburizing, the carbon source, typically natural gas (or propane), composed largely of methane, is introduced into the furnace through an inert gas such as nitrogen (carrier). Carbon and nitrogen Sources are monitored and mixed outside the furnace in endothermic generator systems in which gases

Pass through a heated Areas containing a catalyst (Figure 7 and Figure 8). When the mixed gas leaves the Mixer en is rapidly cooled to prevent Carbon formation and sent to the furnace in such a way that the carbon can then diffuse into the steel [3].







Figures 11. Main features of a vacuum furnace with HPGQ
Figures 12. The key features of a vacuum hardening furnace
Figure 13. Example of LPC simulator summary screen

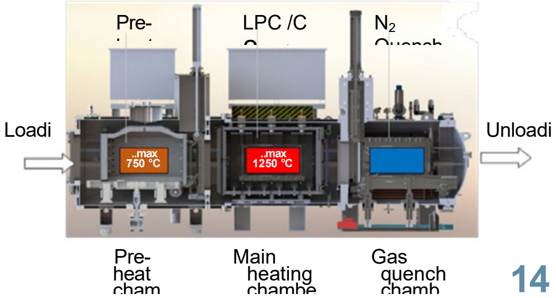
to obtain deeper treatments with a higher carbon content. All this in less Time. "The Carbon potential of an atmosphere (in the furnace) at a specified temperature is defined as the Carbon Content of Pure Iron that is in thermodynamic equilibrium with the atmosphere. The carbon potential for the furnace atmosphere Must Be greater than the carbon potential for the Surface of the Workpieces Know that carburizing takes place in such a way that spontaneous. It is the Difference in Carbon potential that provides the driving Force for carbon transfer to the parts" [1]. This is due to the fact that the carbon potential of the furnace's gaseous environment is higher than that of steel and when the temperature of Workpiece reaches 1700°F [925 °C], the surface of the steel becomes highly Active and allows excess Carbon in the atmosphere to Spread into the component. Rising temperatures drastically affect the rate in The Austenitic phase; for example, a Treatment at 1700°F [925°C] is about 40% faster than a treatment at 1600°F [870°C].

Disadvantages of gas carburizing

1700 °F [925 °C] seems to be the Optimum carburizing temperature two to the construction characteristics of the furnaces; Higher Temperatures would generate excessive deterioration, especially in insulating materials. Due to limitation to 1700 °F [925 °C], There is no significant way to Accelerated the Instalments of carbon diffusion in austenite beyond a certain Value. Inits Early years, the Gaseous Cementation proved to Be a process that was difficult to control, as it was based on the work of personnel who manually removed the material from inside the furnace,

This obviously translated into a depth of Treatment very variable. This randomness and demand from industries for more precise and reliable results have led to the introduction of the Process of monitoring the atmosphere by means of probes. The oxygen Probe Gave the furnace the ability to measure the residual oxygen content within the atmosphere from which it was then possible to identify the carbon potential of the atmosphere [5]. However, controlling the carbon potential for a Given cementation process was and remains Complex. Multiple Systems are needed (figure 8) to haveproper control of the atmosphere and dew point. Toilet Vapor in the furnace atmosphere has a direct impact on the carbon potential. Control of the dew point is fundamental for an effective cementation. The catalyst Inside the endothermic generator runs out over time, requiring monitoring and replacement when the reaction is no longer sufficient. An excessive level of soot inside the catalyst will affect its performance and require burnout. When an Oven has been Idle for a Long time or has completed a burnout for soot removal, the amount

The New Gas needed to return to a given carbon potential is very High than one Might expect. Over Time (typically 12-24 hours) the amount of enriching gas needed to maintain carbon potential decreases. at a regime Value . This is a process called "furnace conditioning" and is when carbon accumulates in the furnace.



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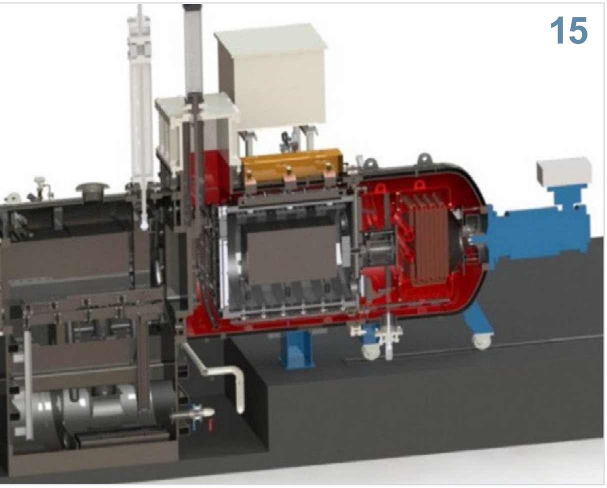

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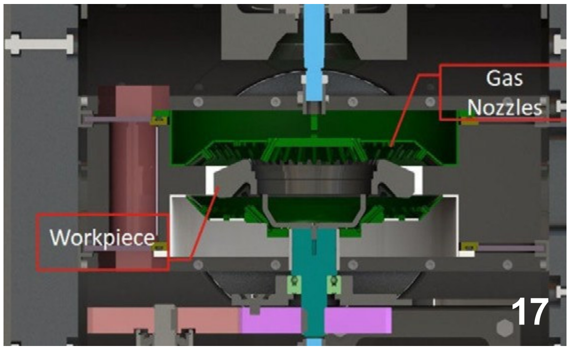
low-temperature areas such as cracks between bricks. However, while the oven continues to work, there.

These are some areas where soot Will Continuous to Settle and Over Time this will have an impact on capacity furnace carburizing [1]. Carburizing Atmospheres are highly toxic and highlyflammable and, when mixed with air, Form explosive gas mixtures. A safety Programs emphasizing furnace Operator Training and Preventive maintenance should be established and respected for all heat treatment operations using controlled atmospheres. The Atmospheric gas discharged from the furnace into the operating environment Must Be burned to Censorship that the Poisonous Carbon Monoxide is converted into carbon dioxide. Flames must always be kept burning every time an oven door opens[1]. Intergranular Oxidation (IGO) occurs when Steel is exposed to oxygen Atoms at Temperatures High. The oxygen present comes from the decomposition of the process gas and slowly spreads on the Grain Edge. This oxygen diffusion then chemically combines with existing Elements favoring chemical reactions. IGO manifests itself Asmicroscopic cracks in the Surface Up to about 0.006 "Deep. Sometimes this depth Can Reach much Greater Values due to the cementation Time Temperatures and composition of the gas. In atmosphere ovens, IGO training is not preventable and its removal Must Be carried out by grinding, suitable mechanical Process . The only other Way to Deleted IGO is to do heat treatment within an oxygen-free environment As in the case of low-pressure cementation (LPC). In this houses a vacuum furnace removes the oxygen present inside the chamber through a pumping System heating mountain. Although the Ability to monitor Temperatures and gas composition has improved, there are still numerous limitations, including Furnace Equipment |. same, the need for dangerous operations, depths often little controllable and formation of IGO. LPC Cementation was born when a method of improving processesand Standards was sought.



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Figures 14. HPGQ semi-continuous vacuum furnace [three chambers] [6]

Figures 15. Two Chambers: vacuum furnace with HPGQ and oil hardening [6]

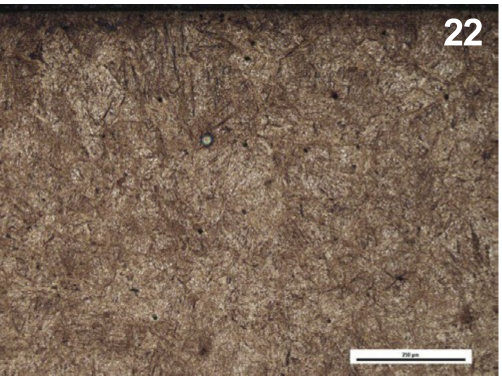
Figure 16. One-piece flow vacuum furnace with LPC and HPGQ chamber dedicated to part [7]

Figure 17. HPGQ chamber dedicated to the manifold .part and rotational Hearth [7]

Figures 18. Typical hardening tank for well carburizing [6]

Low pressure carburizing in vacuum furnaces (LPC)

Low pressure carburizing in vacuum furnaces (LPCs) Differs from gas carburizing in the atmosphere, as the name suggests, since It occurs at lower pressures than atmospheric pressures. This therefore requires that the Process Be carried out in a vacuum furnace instead of atmospheric furnaces. LPC found its origins in the 1970s, where early adopters used propane as a carbon source. Propane, however, generates heavy soot inside the oven. This prompted industry to further improve the Process and, in 1990, acetylene was introduced as a carbon source . This uses the same chemical reaction As hydrocarbon gases at low pressures without the undesirable effects of soot. This is due to the capacity of the steel to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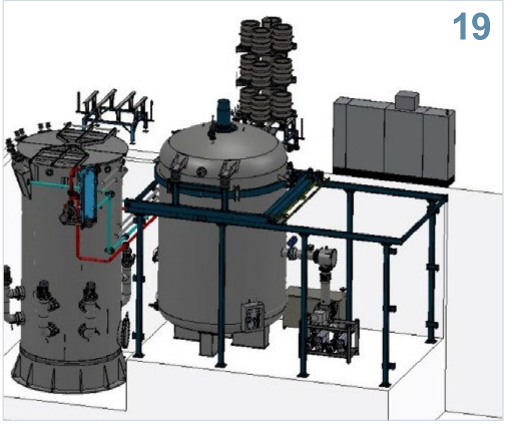
catalyze and decomposed acetylene Carbon molecules by diffusing them in its Surface [5]. The LPC Process consists of loading the furnace, making the vacuum by removing oxygen from the chamber, heat to the desired Austenization Temperatures , typically between 1660-1750°F and then Start with the Actual Treatment . The LPC process consists of a Series of Acetylene diffusions in which Acetyleneis precisely introduced into the heating chamber by means of regulators.

flow at approximate pressures of 8 torr [10 mbar] followed by the Diffusion phase where Carbon Enhanced that has saturated the Surface of the steel spreads towards the heart of the components. This cycle is repeated with variable Times As needed so as to obtain the desired treatment depth (ECD). The alternating step model is necessary because the catalytic Decomposition (or cracking) of acetylene occurs much faster than the diffusion of carbon in steel [5]. Ounces the ECD is reached and depending On the alloying elements, the charge can Be switched off directly in HPGQ or oil or the temperature Can Be lowered to a temperature of 1500-1550°F for stabilization of the material before quenching. Vacuum furnaces can also Be Supplied in Multiple configurations similar to traditional atmospheric ovens in such a way that they can be produced in the types "continuous", "semi-continuous" and "batch" with both horizontal and vertical orientation. As mentioned above in other by the geometry of the components and the grade of the material. Vacuum furnaces can also be supplied with miscellaneous Means of quenching. The most Common constructions of LPC vacuum furnaces are with single-chamber batch System , which use a flow of acetylene and predict a High pressure hardening (HPGQ) as shown in the figure 9 . When the hardenability of the alloys is not such as to allow an HPGQ Treatment, an Oven that provides oil hardening can be used. Another advantage of an LPC vacuum furnace is that the horizontal batch System, shown in Figures 9, Can Be equipped for gas hardening at pressures Up to 25 bar. Pressures quenching up to 25 bar with hardening gas distribution nozzles arranged at 360° around the hot Areas of the furnace and in the front partprovide a less aggressive hardening than that in oil, providing the necessary hardness, all while minimizing the distortion. Figure 11 shows the Main components of an HPGQ furnace that may Include a Suffocating Hardening Agent high power (up to 600 HP), a High efficiency heat Exchanger and an ASME Certified pressure Vessel to contain pressure quenching gas. Gases typically used Includes nitrogen, Helium and/or argon depending on Process requirements . When a Steel alloy requires a faster hardening Requirements, an LPC System Can Be used On a Multi-chamber vacuum hardening furnace. In this system, the heating chamber and the quenching chamber are isolated from each other. In a double-chamber Solution , a charge is placed in the quenching zone on a transfer mechanism.

Once both chambers are depressurized and oxygen is removed, the internal pressure and Thermal ports interconnect. They are opened for the Transfer of Charge from one chamber to another. The charge is then heated to austenization Temperatures and the process LPC Can Begin. Upon completion of the treatment, the interior doors

Figures 22. A micrograph of the resulting microstructure: martensite with approximately 10% austenite retained (100x magnification)
Figure 19. Pit-LPC system model [5]
Figures 20. Cross-sectional Pit-LPC System
Figures 21. Pit-LPC Oven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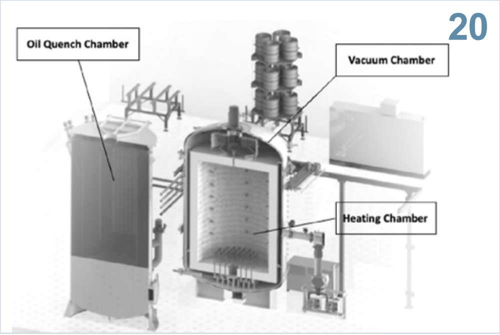
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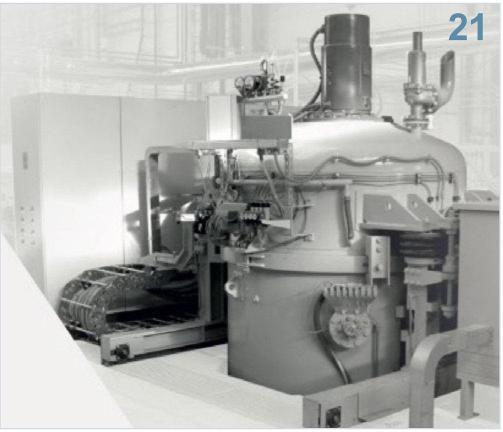
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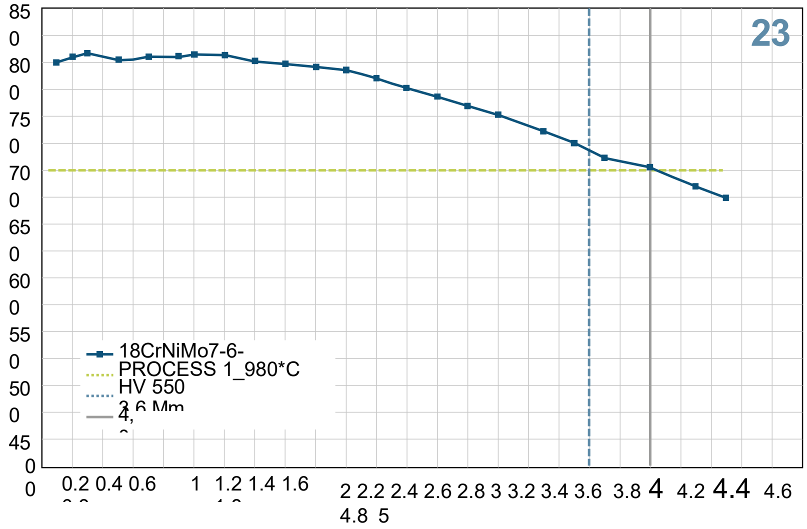

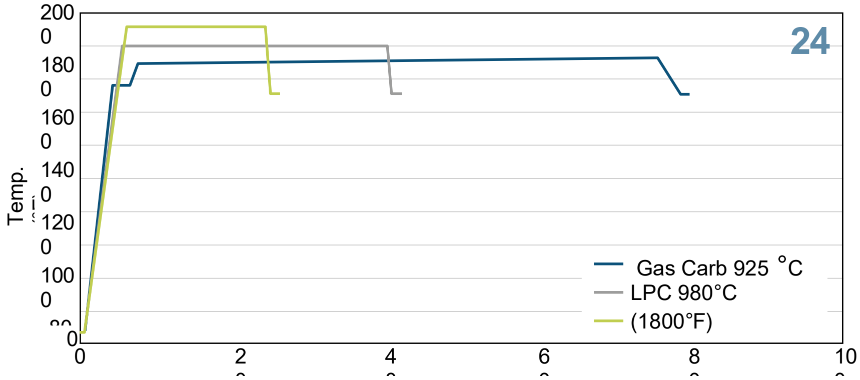

Figures 23. The hardness Profile resulting from the LPC process 1800°F (980°C) **Figures 24.** The Timing of the carburizing Cycle resulting from the cycles

Advantages of low-pressure carburizing in vacuum furnaces

Traditional furnaces for carburizing have limitations on maximum operating temperatures due to the materials used for insulation and heating. Their Temperatures Ranges are typically Limited to 1700°F [925°C] while vacuum furnaces have Values temperature ratings Up to 2400 °F [1310 °C]. This is due to to the fact that oxygen is removed from the furnace through the pumping, thereby preventing the reaction of oxygen and its degrading effects on insulating and heating elements.

With this Ability of the vacuum furnace to heat up above 1700°F [925°C] the Carbon at much higher speeds. LPC provides Fast, effective, effcient, uniform and precise carburizing for regular or densely loaded fillers even on complex shaped parts. The process time can be reduced Up to 5 Times depending on the operating temperature, compared to traditional carburizing, drastically reducing overall processing times and costs. The continuous Development and Progress of LPC has LED to the implementation of sophisticated process modelling and control methods (figure 13) that allow LPC to Be a Direct Substitute for gaseous cementation in all those sectors that require hardening.

of its components. The Simulation software offers the Possibility to Develop and Simulated Cementing processes before Performing the real Treatment . The simulation algorithm performs calculations based on steel grade, Temperatures dimensions and dimensions shape of the parts and the cemented surface area, and returns the optimized sequence of carburizing and diffusion steps, As well as the expected Carbon Profile within the parts. Boost and diffusion sequences Can Be imported into the furnace management system, Eliminating potential human error in data entry. Advances in automotive and aeros designnow more than ever look to LPC as a Solution for transmission components.

The industry is placing increasingly stringent demands On material performance and, as a result, basic materials are continuously being updated to improve product performance. LPC is a perfect Solution for current and future needs and, where applicable, HPGQ Can Be the optimal Choice as it brings less distortion than oil quenching . Not only are there single-chamber and double-chamber vacuum furnaces, but such furnaces can also Be configured in miscellaneous other multi-chamber solutions. These are represented in Figures 14 to 17. Additional advantages of LPC treatment in a vacuum furnace compared to traditional gas carburizing with oil quenching include: decreased distortion; elimination of intergranular oxidation (IGO); no decarburization; Elimination of endothermic generators; high productivity; high precision and feasibility of carbon penetration; reduction of carburizing times; Lower Process costs ; excellent uniformity; Unlimited Carbon Transfer; guaranteed process repeatability; no CO2 emissions; environmental friendliness. These Benefits are not Limited to the Aerospace Industry and

Gas Carburizing @ 925 °C (1700 °F) - Cycle Phases
Heat Up to 850 °C (1560 °F)
Immersion at 850°C (1560°F)
Heat Up to 925°C (1700°F)
Carburizing Cooling to 1500°F (820°C)
Oil hardening at 180 °C (360 °F)
Heat Up to 850 °C (1560 °F)

TABLE 1 - BASIC PARAMETERS OF THE ATMOSPHERIC CEMENTATION PROCESS

LPC @ 980°C (1800°F) Cycle Phases
Heating Up to 1800°F (980°C)
Carburizing
Cooling and immersion at 1500°F (820°C)
Oil hardening at 360°F (180°C
Heating Up to 1800°F (980°C)

TABLE 2 - DESCRIPTION OF THE LPC CEMENTATION PROCESS AT 1800°F (980°C)

LPC @ 1040 °C (1900 °F)
Heating Up to 1900°F (1040°C)
Carburizing
Cooling and immersion at 1500° F (820°C)
Oil hardening at 360°F (180°C)

TABLE 3 - DESCRIPTION OF THE LPC CEMENTATION PROCESS AT 1900 °F (1040 °C)

ATM PIT	PIT LPC Process		Parameter
LPC carburizing Temperatures	1.700	1.800	1.900
Duration (hours)	80	42	26
LPC Process duration compared to gas carburizing	100%	52%	33%
Annual processes (6500 hours/year)	81	155 250	
Improved productivity	100%	190%	308%
Total Cost of Cycle Utilities$	$1,077.67	575.96$	488.07
LPC Utility costs compared to gas carburizing	100%	53%	45%
CO emissions ($_2$metric tons)0.59≈0		≈0	

TABLE PROPERTY 4 - SUMMARY OF POTENTIAL PRODUCTIVITY AND SAVINGS OF THE LPC PIT SYSTEM COMPARED TO GAS CARBURIZING IN AN ATMOSPHERE WELL FURNACE ON

Distillation in Atmospheric Well Historically, atmospheric cementation has been the method of choice for the cementation of large and Heavy Pieces. As mentioned in the introduction, this is mainly due to the load capacity of Well furnaces with High working casings. The furnaces Will Be autonomous Systems that will have an accompanying hardening tank Next to the furnace (figures 18). In Well Systems , the load is typically supported by an aerial handling System (often a crane). During the Transfer from the furnace to the hardening tank, the presence of the Crane provides a dangerous working environment two to the intense radiation of heat emitted by the load and the risk of Fire if the load is extinguished in a toilet [5]. Additional problems associated with Well Cementation Includes: Long Process Times ; a flammable atmosphere (endogas and methane); expensive maintenance for all furnace components and circulation NSAIDs; conditioning of the oven; process monitoring (using sample coupons or continuous monitoring devices); presence of intergranular oxidation. These Disadvantages show that it is necessary to change the approach Traditional to Cementation in the Well. LPC represents that alternative that

The Pit LPC Oven System

The LPC Pit Furnace System offers an innovative approach that brings together the traditional cold-wall design of a vacuum furnace with metal bar embedded in a ceramic fiber coating that allows them to Resist Oxidation when exposed to oxygen at high temperatures. In a traditional graphite-coated vacuum furnace it can be exposed to air because graphite would oxidize immediately by reacting with oxygen at high temperatures. Since the Pit LPC Oven includes the necessary insulating and heating components that Resist Oxidation ounces the LPC Process has been completed, the furnace can be opened (while still at typical LPC temperatures) and the hot load Can be removed and transferred to its adjacent quenching tank As illustrated in figures 19 to 21 [5]. In addition, the furnace is equipped with a water-cooled heat Exchanger and a Shutdown fan, meaning a load Can Be cooled slowly if Rapid hardening is not required. to oil.

The stand-alone furnace System with LPC includes the following features:

- Working area 70" (1800 mm) diameter 120" (3000 mm) Deep
- Gross freighter mass Up to 17,600 Lb. (8000 kg)
- Heating Power of 360 Kw
- 2012°F Max Temperatures [1100°C]
- Integrated vacuum pumping System
- $^{10-2}$ torr (10-2 mbar) vacuum Interval
- Acetylene As a Carbon Source Gas and includes an LPC Process Simulator.
- To limit distortion, forced nitrogen cooling is also included for to faster Temperatures Drop before quenching.

A houses study On Pit LPC ovens To Highlight the advantages of using a Pit LPC oven system for the cementation of large and heavy parts, a Case study on a load with the following characteristics was completed [5]:

- Mass: 13,230 Lbs (6000 kg)
- Steel grade : SAE 4820 (18CrNiMo7-6)
- Desired Effective Case Depth (ECD): 0.157" (4.0mm) at 50HRC
- Concrete surface : 215 Sf (20 sqm)
- Carburizing temperature: 1700 °F (925 °C)

This load was simulated both in a gas carburizing Cycle in A traditional well-type furnace in the atmosphere and in the Pit-LPC System. The Comparison is based On both a carburizing furnace Atmospheric gas in a Plant that On LPC date recovered in the Pit Oven Laboratory Style-LPC . The Phases used in the gas carburizing Cycle are shown in Table 1. In contrast to the basic atmospheric cementation process, the process LPC was simulated at two different Temperatures to understand the effect of carburizing temperature On Cycle Time. The corresponding LPC Cycle Phases are shown in Table 2 for 1800 °F (980 °C) and in the Table 3 for 1900°F (1040°C). Table 3 then shows the LPC Cycle Phases used at 1900°F (1040°C).

Annual Processes	ATM PIT	PIT LPC
155	Temperatures: 1700 °F Total Cost : $ 166,782 CO_2 emissions: 91.5 tonnes	Temperatures: 1800 °F Total Cost: $89,136 CO_2 emissions: ≈0 tonnes
250	Temperatures: 1700°F Total cost: $269,417 CO 2 emissions: 147.5 tons	Temperatures: 1900 °F Total cost: $122,017 CO_2 emissions: ≈0 tons

TABLE PROPERTY 5 - SUMMARY OF POTENTIAL ANNUAL PIT LPC COMPARED TO GAS CARBURIZING IN AN ATMOSPHERE FURNACE

LPC well case study: results and analysis

All three Cementing processes were combined with a hardening and tempering in Oil in which all three processes produced similar Metallurgical results . Micrography in Figures 22 illustrates the resulting Structure: martensite with about 10% austenite retained [5]. The microstructure shown in Figure 22 is matched to the hardness profile measured in Figure 23 and shows that the surface hardness reached almost 62 HRC or [770 HV] with ECD Equal to 0.157" [4 mm] As defined by a 52.5 HRC or 550 HV. Granulometry maintained appropriate ASTM Size - level 7. This Profile was the Result of the LPC 1800 °F (980 °C) Process [5].

To achieve the hardness Profile shown in Figure 23, the necessary cycle Time is represented in Figures 24 (1800°F). It is important to note that gas carburizing conducted at 1700°F (925°C) takes almost 80 hours to complete. Meanwhile, LPC conducted at 1800 °F (980°C) took only 42 hours to complete, a 50% reduction in the time needed. A further increase in the carburizing Temperatures to 1900°F (1040°C) reduced the Time to 26 hours, corresponding to a 68% reduction, Figure 24 (1900°F). The Cycle Time produced by the Pit Style-LPC has allowed to drastically reduce consumption by eliminating at the same time, emissions of Carbon dioxide and carbon monoxide. Impressive Cost savings aren't the only advantage of Pit Style-LPC. The time savings also resulted in increased productivity compared to gas cementation. When evaluating a five-(5) day operating week, the unit Pit Style LPC has the potential to be drastically more productive. If cemented at 1800 °F [980 °C], the reduction in cycle time would almost Double the Total Number of cycles per year. When assessing carburization at 1900°F [1040°C], the number of cycles triples. Table 4 shows the increase in productivity and related savings for Cycle [5]. To Better Shown the LPC savings compared to atmospheric hours a year. At 1800 °F [980°C] 155 cycles are achievable with one (1) LPC well furnace only , in contrast to the gas carburizing Process which requires two (2) Well furnaces. The Total Processing cost would amount to $166,782 while the Pit-LPC costs would only be $89,136 . That's a total saving of $77,646. Switching to a higher carburizing Temperatures of 1900°F [1040°C], 250 cycles could be achieved with one (1) LPC well system, compared to three (3) well furnaces in the atmosphere that would be necessary for the same Number of cycles in a year. Annual Cost savings would then rise to $

Conclusions

Pit LPC is an Innovative Furnace System that Replaces traditional atmospheric carburizing Solutions. This approach is able to Handle the same loads with deep ECD, reducing at the same time Process Times and costs. These Benefits dramatically increase ROI when converting from atmospheric carburizing to LPC while Eliminating Carbon emissions. Associated with gas carburizing . •

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