



**Understanding LPC:**  
Fundamentals and Latest  
Advances in Low Pressure  
Carburizing Technology

**SECO/VACUUM**  
*We support your success.*

## Program Registration



BNP Media has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.



## Copyright Materials

This educational activity is protected by U.S. and international copyright laws. Reproduction, distribution, display, and use of the educational activity without written permission of the presenter is prohibited.

© SECO/VACUUM 2021



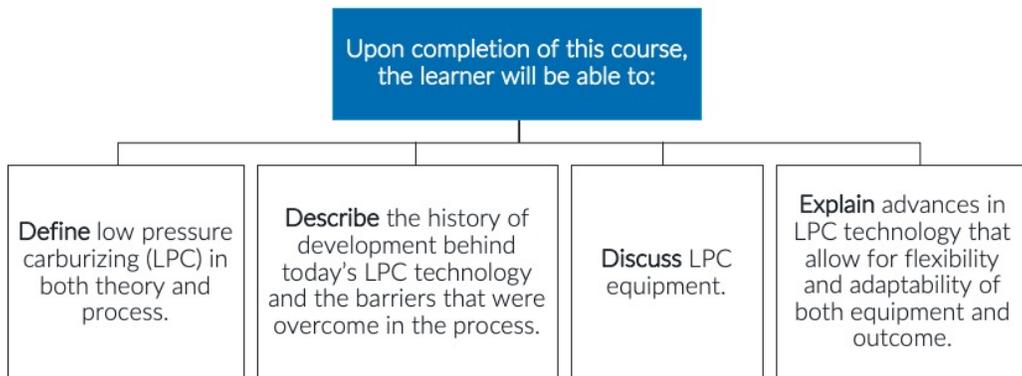
## Course Overview

This course provides an overview of low pressure carburizing (LPC) technology, laying the foundation for understanding today's modern equipment and processes, and the evolutionary path that LPC technology has traversed, from the 1960s to today.

Discussion of standard equipment, as well as advanced set-ups that accommodate equipment and product flexibility, are provided. Case studies demonstrate both the process and flexibility of LPC to garner excellent outcomes for industrial applications.

This course provides an overview of low pressure carburizing (LPC) technology, laying the foundation for understanding today's modern equipment and processes, and the evolutionary path that LPC technology has traversed, from the 1960s to today. Discussion of standard equipment, as well as advanced set-ups that accommodate equipment and product flexibility, are provided. Case studies demonstrate both the process and flexibility of LPC to garner excellent outcomes for industrial applications.

## Learning Objectives



Upon completion of this course the student will be able to:

Define low pressure carburizing (LPC) in both theory and process.

Describe the history of development behind today's LPC technology and the barriers that were overcome in the process.

Discuss LPC equipment.

Explain advances in LPC technology that allow for flexibility and adaptability of both equipment and outcome.



Section 1 –  
Introducing LPC

## Introducing LPC

**Today's low pressure carburizing (LPC) presents the following advantages:**

- Carburizing precision and uniformity
- Carburizing gas efficiency
- Energy consumption and post process product emission
- Safety



Although discovered in the 1970s, vacuum carburizing began to be used in industry worldwide about two decades ago and now serves as an advantageous alternative to atmosphere carburizing for many case hardening applications.

In comparison to traditional atmospheric technology, today's low pressure carburizing (LPC) presents many advantages, especially in carburizing precision and uniformity, carburizing gas efficiency, energy consumption, and post process product emission.

## Introducing LPC



Low pressure carburizing is characterized by: a very high ratio of carbon transfer at the interface, which results in very rapid transport of carbon to the charge surface. This makes the carburizable surface area a key variable.

# Introducing LPC

Carburizing and the LPC advantage:



## LOW PRESSURE CARBURIZING – FUNDAMENTALS

- Process temperature – above **850°C**, typical **900-980°C** and up to even **1100°C**
- Process pressure **up 15 mbar abs**

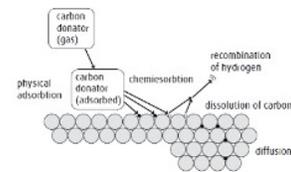
### Process phases:

- **Carburizing**  
(gases transfer – carbon carriers (donator) – into the work zone)
- **Dissociation**  
(thermal or catalytical decomposition of process gases to obtain a high concentration of carbon in a relatively very short time)
- **Adsorption**  
(i.e. the deposition of free atoms of saturated component at the border of solid phase as a film with a thickness similar to the diameter of an atom)
- **Diffusion**  
(diffusion of carbon into the depths of the material)

### Catalytical decomposition



essentially it means that it will break down into its elemental constituents in the presence of an iron catalyst.



LPC uses 4 total phases: carburizing (where gases are introduced into the working zone of furnace with carbon carrier donors), dissociation (thermal or catalytical decomposition of process gases to obtain a high concentration of carbon in a relatively short time), adsorption (the deposition of free atoms of saturated component at the border of solid phase as a film with a thickness similar to the diameter of an atom), and diffusion (the final phase, where carbon diffuses into depths of material). Unlike atmosphere carburizing, where the case hardened layer (case depth) is determined by the temperature and the by the gases present in the furnace, LPC is driven by the carbon present on the surface of the steel which helps to determine the case depth.

## Introducing LPC

Carburizing and the  
LPC advantage

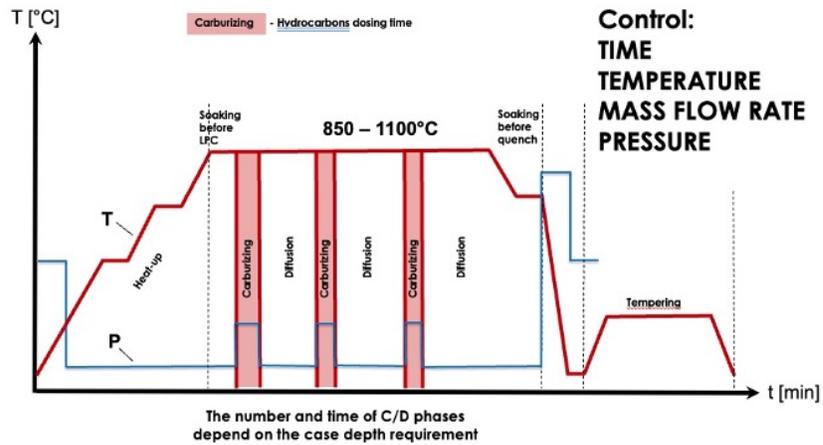


Low pressure carburizing, thanks to its advantages, is now becoming a more popular option. Some industries have used it for many years in select applications. However, advances in process controls have allowed for it to have distinct advantages over atmosphere carburizing.

These qualities are both technical and economic. Advances in gas flow controls and process modeling have made it more competitive with atmosphere carburizing. Also, the potential to carry out LPC at elevated temperatures can shorten process times, resulting in savings.

# Introducing LPC

## LOW PRESSURE CARBURIZING – FUNDAMENTALS



Successful LPC requires careful matching of the quantity of carbon to the surface area to be carburized. This requirement makes careful gas flow control essential. Dosing of the carbon source gas can be determined using the LPC process simulator, which is built into the furnace control system (some manufacturers do this, but not all). Dosing is done by precision valves to ensure repeatability of mass and flow settings.

## Introducing LPC

- **Carburizing Process Elements**

- Time – a function of the material and the effective case depth
- Temperature – a function of the material and carbon source gas
- Carbon Source Mass Flow Rate – a function of the carburizing time and surface area
- Pressure - typically around 8 torr



What parts of the carburizing process do we control? There are four key elements: Time, temperature, mass flow rate, and pressure. Time refers to time of the phases or segments of the cycle recipe, temperature control is necessary for uniform results, mass flow rate dictates the quantity of carburizing gas introduced into the furnace, and finally, the pressure required.

## Introducing LPC: Advantages

### **Advantages in the vacuum carburizing process:**

- Higher carbon flux – vacuum environment makes the transfer of carbon to the steel surface faster
- Absence of intergranular oxidation – no igo because of vacuum environment
- Faster processing – capable of higher temperatures due to type of equipment
- Process flexibility allows treatment of densely packed loads, blind holes parts
- No decarburization of steel can occur due to lack of carbon potential atmosphere
- Process and cycle flexibility
- Creation of any desired carbon profile, due to simulator capability – greater flexibility
- Easy modification of surface carbon content
- Processing methods produce very uniform case and carbon profiles throughout the parts and especially blind holes parts

Advantages in vacuum carburizing:

Higher carbon fluxes – vacuum environment makes the transfer carbon to the steel surface faster

Absence of intergranular oxidation – no igo because of vacuum environment

Faster processing – capability of higher temperatures due to type of equipment

Process flexibility allows treatment of densely packed loads, blind holes parts

No decarburization of steel can occur due to lack of carbon potential atmosphere

Process and cycle flexibility

Creation of any desired carbon profile, due to simulator capability – greater flexibility

Easy modification of surface carbon content

Processing methods produce very uniform case and carbon profiles throughout the parts and especially blind holes parts



## Introducing LPC: Advantages

### **Advantages in quality:**

- High uniformity and repeatability within the parts and loads
- Simulation promotes achievement of the required carbon profile
- Process flexibility allows to treat densely packed loads, blind hole parts
- Ideal surface quality – no oxidation
- Typically less distortion (LPC + HPGQ)
- Very little grinding or cleaning needed afterwards
- No intergranular oxidation (IGO)

### Advantages in quality:

High uniformity and repeatability within the parts and loads  
Simulation assists in making the exact requested carbon profile  
Process flexibility allows to treat densely packed loads, blind holes parts  
Ideal surface quality  
Typically less distortion (LPC + HPGQ)  
Very little grinding or cleaning needed afterwards  
No intergranular oxidation (IGO)

## Introducing LPC: Advantages

### **Advantages in environmental impacts:**

- Process is clean, safe, and simple to operate and easy to maintain
- Working conditions are excellent
- Minimal consumption and emission of process gases
- Less post heat treatment options
- No costs of byproduct neutralization



Advantages in environmental impacts:

Process is clean, safe, and simple to operate and easy to maintain

Working conditions are excellent

Minimal consumption and emission of process gases

Less post heat treatment options

No costs of byproduct neutralization – cleaning of tars or carbon monoxide scrubbing resulting from endogas generation



## Introducing LPC: Advantages

### **Advantages in production process impact:**

- Easy integration and automatization into manufacturing line
- No furnace atmosphere conditioning needed
- Flexibility in operation
- Consumption of energy, process gases by the equipment and process only when needed, due to the nature of the vacuum operation

Advantages in production process impact:

Easy integration and automatization into manufacturing line

No furnace atmosphere conditioning needed

Flexibility in operation

Consumption of energy, process gases by the equipment and process only when needed, due to the nature of the vacuum operation



## Introducing LPC: Advantages

### **Advantages in economics:**

- Fast processing, increases productivity
- Shorter cycles, less energy and gas consumption – lower production costs
- Less distortion, lower post machining costs
- No equipment conditioning – no idling costs
- Higher profitability

Advantages in economics:

Fast processing, increases productivity

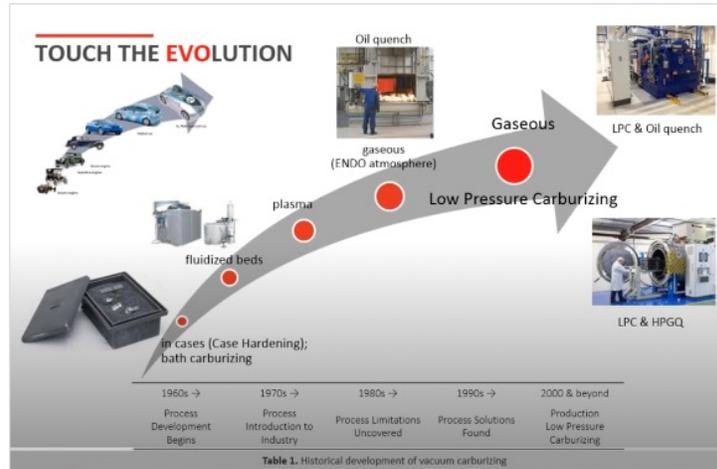
Shorter cycles, less energy and gas consumption – lower production costs

Less distortion, lower post machining costs

No equipment conditioning – no idling costs

Higher profitability

# A Brief History of LPC



Carburizing is a surface hardening method for steel that has a storied history. First developed in the 1920s, the process went through several evolutionary steps before arriving at the ever-popular gas carburizing process in the 1950s. By the late 1960s, this process, although popular, was labor intensive and hard to control. Carbon diffusion into the steel surface is directly related to the gas phase carbon concentration, which was difficult to monitor, especially at elevated temperatures. During this era, various methods were developed to monitor this process. Unfortunately, none were extremely effective at providing reliable readings which effected the final case depth [1].

## A Brief History of LPC



Without the capabilities of modern microprocessors, the only reliable way to monitor the process was to use shim stock. Extracting these coupons on a regular basis and weighing them throughout the carburizing cycle provided the means to track the development of the case hardened layer. By the late 1960s, this practice was in use by the industry [1].

Although reliable, extracting samples periodically over the course of an eight, twelve, or sixteen hour-cycle had its challenges. The periodic nature of this process required labor resources and constant monitoring. As a result, industry began the search for alternatives for process control. This led to the development of new process monitoring devices such as the oxygen probe. The oxygen probe had the ability to monitor the residual oxygen present in the furnace atmosphere which could then be directly tied to the carbon potential of the furnace atmosphere [1].

## A Brief History of LPC



Monitoring in real time became a reality with the introduction of the oxygen probe to the gas carburizing process. The probe also improved the ability to control the atmosphere carbon potential without operator interaction. Enriching gas was able to be added in precise quantities under this method, allowing adjustment of the furnace atmosphere to achieve the required carbon potential. It was a revolutionary breakthrough. However, despite this newfound capability, gas carburizing still suffered from numerous limitations, including the furnace equipment itself. As a result of these limitations, a better method of carburizing was discovered -- low pressure vacuum carburizing or LPC. [1]

## A Brief History of LPC

LPC arrives  
and evolves



The search for better controls created the opportunity for LPC technology. LPC differs from atmosphere gas carburizing in that it is carried out at pressures below atmospheric pressure, which requires use of a vacuum furnace instead of the traditional atmosphere furnace equipment.

Early attempts at this process in the early 1970s used propane as the carbon source gas. However, using propane as a source gas produced vast amounts of soot and other carbon based contaminations, leaving the furnace in need of maintenance. With propane, LPC was an impractical method. However, by the 1990s, a better general understanding of the reaction chemistry of hydrocarbon gases at low pressures revealed the potential of acetylene as a carbon source for LPC. [1]

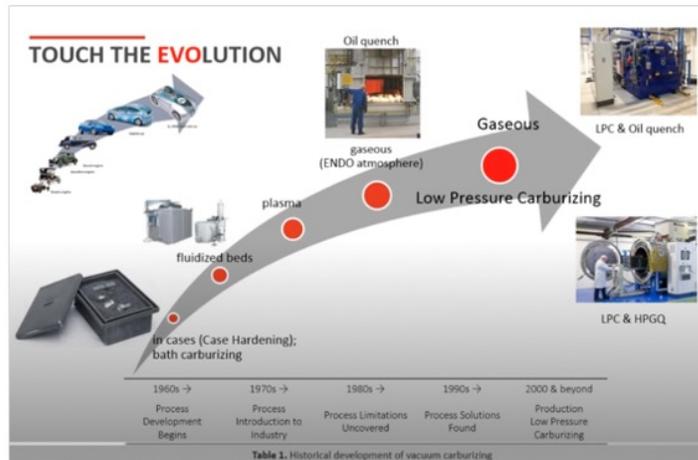
## A Brief History of LPC



Ken Kubota of the JH Corporation in Japan patented the first such process in 1996. Acetylene ( $C_2H_2$ ) provided what other carbon source gases could not: the potential to achieve the desired case depth with virtually no soot, thanks to steel's ability to catalyze its decomposition. In the cases where acetylene cannot provide adequate carbon, it is combined with other gases such as ethylene ( $C_2H_4$ ) to increase the carbon supply for a given material.

Regardless of whether acetylene only, or a gas mixture is used, a furnace is equipped with highly accurate gas flow control equipment. Processing an alloy capable of hardening by high pressure gas quenching (HPGQ) can also be used for LPC. [1]

## A Brief History of LPC



Since the new development of the 2000s, LPC has offered a distinct and advantageous alternative to atmospheric furnaces.

New equipment designs, control of process, simulator software, and processing methods, as well as the use of acetylene instead of propane or methane as carrying gas, all assure excellent quality, increased productivity, and capacity.

## LPC Equipment and Processes



The typical LPC process involves the load being placed in a cold chamber which is then heated to the austenitization temperature. Typically, this is in the range between 1660 °F and 1750 °F (870 °C and 950 °C). Acetylene is then added at a flow rate adequate to maintain a furnace pressure of about 8 torr (10 mbar). A process recipe that alternates between segments introducing acetylene and segments allowing the carbon to diffuse into the material are most common. This alternating segment pattern is needed because the catalytic cracking of acetylene occurs much faster than does the diffusion of carbon into the steel. Once started, the alternating pattern continues until adequate carbon has been introduced and it has been allowed to diffuse to the required depth. This process is then followed by either a high pressure gas or oil quench, depending on the material being case hardened [1].

## LPC Equipment and Processes



This differs from typical gas carburizing where the load is placed in a hot chamber at a similar temperature range but at atmospheric pressure. Here, the carbon source gas (typically a combination of endo-gas and enriching gas), flows through the chamber continuously to generate the appropriate carbon potential. When the carbon potential of the atmosphere is correct, the conditions are maintained to allow carbon to diffuse into the surface of the steel until the desired effective case depth is achieved. Then, the load is transferred to quench, which is typically an oil bath. [1]

## LPC Equipment and Processes

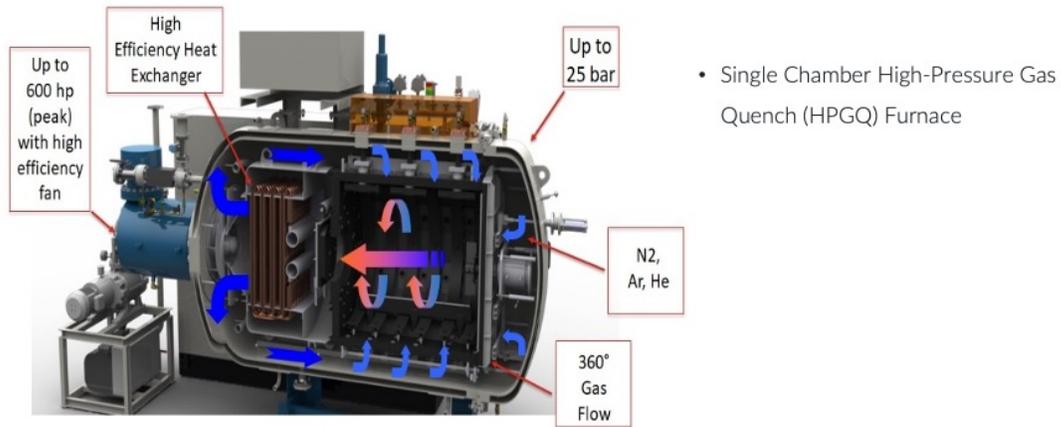


The development of more sophisticated modeling and control methodologies has allowed LPC to take a more prominent role in industries requiring case hardened components, replacing atmosphere gas carburizing. This is especially true in automotive and aerospace power transmission where gears can be made from alloys that are capable of hardening using HPGQ technologies and effective case depth requirements are in the range of 0.040 inches with a required surface hardness of 58 to 62 HRC. Key advantages of the combination of LPC and HPGQ make LPC the preferred choice over traditional gas carburizing and oil quenching in scenarios like those encountered with gears. Those key advantages include:

- Decreased distortion
- Elimination of intergranular oxidation (IGO)
- No decarburization
- High productivity
- High accuracy and repeatability
- Shortened cycle times

These advantages extend LPC to many other applications in industries such as tool and die, energy, and transportation [1].

## Flexibility by Design: LPC Equipment

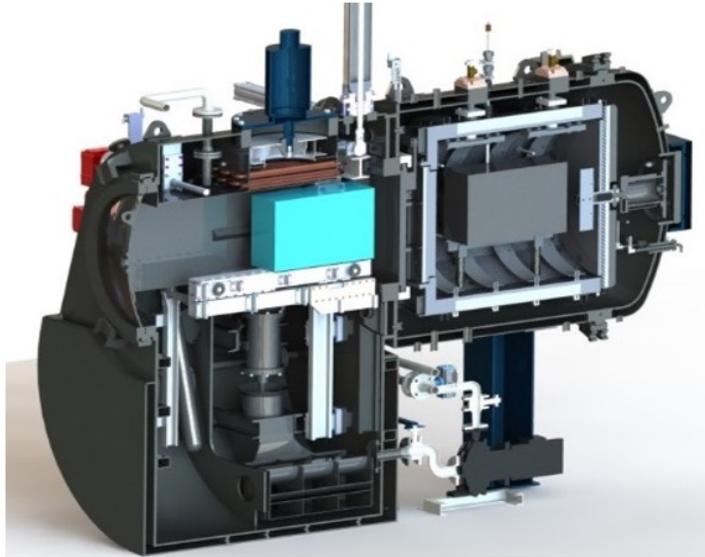


Another advantage of LPC is that a wide array of vacuum furnace equipment is available to support it.

To begin, let's examine the single chamber high-pressure gas quench (HPGQ) furnace. This unit combines LPC and gas quenching at pressures up to 25 bar. This pressure, combined with the ability to quench with gases such as nitrogen in a heating chamber with 360° gas flow ensures that case hardened components reach the required hardness while minimizing distortion.

## Flexibility by Design: LPC Equipment

- Multi-chamber Furnace

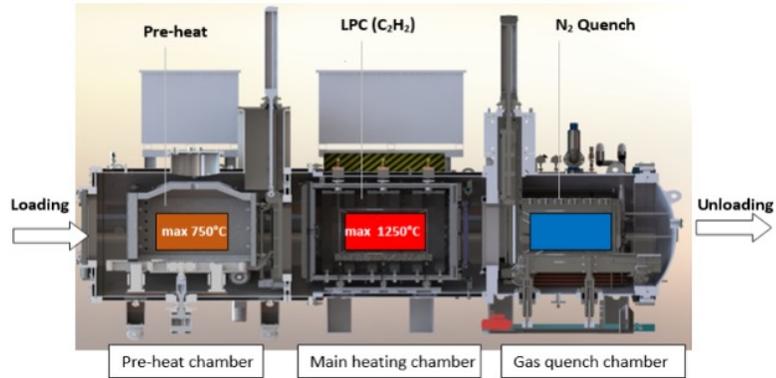


LPC can also be adapted into a multi-chamber furnace to facilitate oil quenching. For instance, an integral quench design features a vacuum heating chamber to support LPC and a separate oil quenching chamber. Here, the load is introduced into the heating chamber through the quenching vestibule with a loader. Once in the heating chamber, the load is heated and LPC is completed. Then, the load is extracted from the heating chamber and moved to the quenching chamber, where it is quenched [1].

## Flexibility by Design: LPC Equipment

### Multi-chamber Furnace

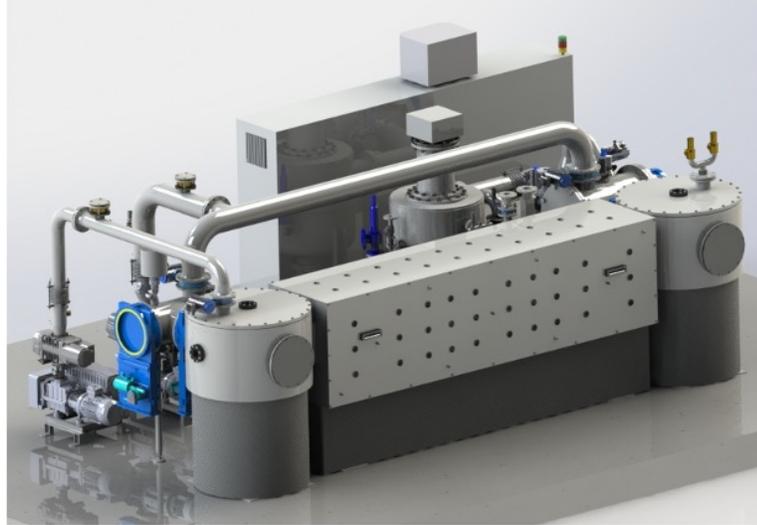
- Semi-continuous environment for higher volume production



The use of multi-chamber furnace arrangements provides LPC with the potential to operate in a semi-continuous environment. This expands throughput potential to higher volumes as required, for example, by the automotive transmission component industry. The addition of a preheating chamber means that the load will reach be partially heated (up to 750 °C or 1,380 °F) before entering the main heating chamber where it reaches the austenitization temperature and LPC is carried out. The load then moves into either a HPGQ or oil quenching chamber. In this configuration, throughput can reach levels nearly twice that of the comparable two chamber furnace [1].

## Flexibility by Design: LPC Equipment

- Continuous Throughput Applications/Single Piece Flow



LPC can also be adapted to continuous throughput applications, or, single piece flow. Here, parts are placed in the furnace one piece at a time. This allows a single workpiece to move through the heating chamber where it reaches the austenitization temperature and LPC is carried out. Then, it reaches a quenching chamber where it undergoes the HPGQ process in nitrogen using pressures up to 10 bar while being rotated. This unique process minimizes distortion and provides individual part traceability [1].

## LPC Equipment: New Adaptations

- Adapting to large diameter or distortion-susceptible workpieces



Although this wide array of furnace equipment provides significant LPC capability, it has its limitations. This is especially true when workpiece size becomes a main consideration. Workpieces that have a large diameter or could suffer from creep-related distortion during the carburizing process are sometimes difficult to accommodate in traditional vacuum furnaces. Instead, these parts are typically processed in a vertical orientation in a pit type furnace.

## LPC Equipment: New Adaptations

- Pit adaptation



Atmosphere pit carburizing is the traditional method used for large or heavy workpieces.

## Limitations of Atmospheric Pit Equipment

### Limitations of traditional atmospheric pit equipment

- Dangerous work environment
- Long process times
- A flammable atmosphere (endogas and methane)
- Maintenance of costly furnace components such as retorts and circulating fans
- Furnace conditioning
- Process monitoring (using sample coupons or continuous monitoring devices)
- Presence of intergranular oxidation
- Furnace conditioning



As shown, the load is often supported by a fixture and moved by an overhead crane between the loading station, furnace, and quench tank. This movement includes the transfer between the carburizing furnace and the quench tank when the load is hot. Although common, this method exposes the operator to a dangerous work environment, not only because of the intense heat given off by the load as it transfers, but also the risk of fire if being quenched in oil. This situation coupled with factors such as:

Long process times

A flammable atmosphere (endogas and methane)

Maintenance of costly furnace components such as retorts and circulating fans

Furnace conditioning

Process monitoring (using sample coupons or continuous monitoring devices)

Presence of intergranular oxidation

Furnace conditioning

These limitations make atmospheric pit less desirable than other equipment choices. LPC provides a safe and cost-effective alternative to this process, but the traditional vacuum furnace equipment is not offered in a pit configuration until now [1].

## Introducing Pit LPC



A pit style LPC system is an innovative design that combines a cold wall vacuum furnace with an oil quench tank. This arrangement provides the platform to carburize large and heavy parts using the LPC process instead of traditional atmosphere gas carburizing. To facilitate this process, where the load must be transferred to the quench tank in air while hot, the furnace has the unique ability to open at processing temperature. Rod style metallic heating elements incorporated into a ceramic fiber lining make this possible due to their ability to resist oxidation. In a traditional graphite or molybdenum lined vacuum furnace, the graphite would quickly oxidize at elevated temperatures. This furnace does not include a retort for containment for the process gas atmosphere [1].

## Introducing Pit LPC



The system analyzed here includes a furnace and quench tank with a working zone of 70" (1800 mm) diameter 120" (3000 mm) depth. This envelope allows it to accommodate a gross load mass of up to 17,600 lb. (8000 kg). A heating power of 360 kW allows it to reach a maximum temperature of 2,012 °F (1,100 °C). The integrated vacuum pumping system allows it to reach the  $10^{-2}$  torr ( $10^{-2}$  mbar) vacuum range, which is sufficient for LPC. The furnace is also equipped with an LPC system which uses acetylene as the carbon source gas and includes an LPC process simulator. Forced nitrogen cooling is also included for faster temperature drop before quenching to limit distortion by quenching [1].

## CASE STUDY: Pit LPC Under the Microscope



### Case Study

To illustrate the advantages of using LPC in this furnace system for carburizing large and heavy parts, a case study was completed on a load with the following characteristics [1]

Mass: 13,230 lb. (6000 kg)

Steel Grade: SAE 4820 (18CrNiMo7-6)

Desired Effective Case Depth (ECD): 0.157" (4.0mm) at 50 HRC

Carburized Surface Area: 215 sf (20 sq. m)

Carburizing Temperature: 1,700 °F (925 °C)

## CASE STUDY: Pit LPC Under the Microscope

### Gas Carburizing @ 1,700 °F (925 °C) Cycle Steps

Heat up to 1,560 °F (850 °C)

Soak at 1,560 °F (850 °C)

Heat up to 1,700 °F (925 °C)

Carburize

Cool to 1,500 °F (820 °C)

Oil Quench

Temper at 360 °F (180 °C)

This load was simulated in both a gas carburizing cycle in a traditional atmosphere pit type furnace and LPC in the Pit-LPC system. The comparison is based on both an atmosphere gas carburizing furnace at a plant and LPC data retrieved in the laboratory Pit Style-LPC furnace. The steps used in the gas carburizing cycle are shown in Table 1 [1].

Table 1. Atmosphere carburizing process description.

### Gas Carburizing @ 1,700 °F (925 °C) Cycle Steps

Heat up to 1,560 °F (850 °C)

Soak at 1,560 °F (850 °C)

Heat up to 1,700 °F (925 °C)

Carburize

Cool to 1,500 °F (820 °C)

Oil Quench

Temper at 360 °F (180 °C)

## CASE STUDY: Pit LPC Under the Microscope

### LPC @ 1,800 °F (980 °C) Cycle Steps

Heat up to 1,800 °F (980 °C)

Carburize

Cool and soak at 1,500 °F (820 °C)

Oil Quench

Temper at 360 °F (180 °C)

Meanwhile, LPC was simulated at two different temperatures to understand the effect of carburizing temperature on the cycle time. The corresponding LPC cycle steps are shown in Table 2 for 1,800 °F (980 °C) and Table 3 for 1,900 °F (1040 °C) [1].

Table 2. LPC carburizing process description at 1,800 °F (980 °C)

#### LPC @ 1,800 °F (980 °C) Cycle Steps

Heat up to 1,800 °F (980 °C)

Carburize

Cool and soak at 1,500 °F (820 °C)

Oil Quench

Temper at 360 °F (180 °C)

Table 3 then shows the LPC cycle steps used at 1,900 °F (1040 °C).

Table 3. LPC carburizing process description at 1,900 °F (1040 °C).

#### LPC @ 1,900 °F (1040 °C) Cycle Steps

Heat up to 1,900 °F (1040 °C).

Carburize

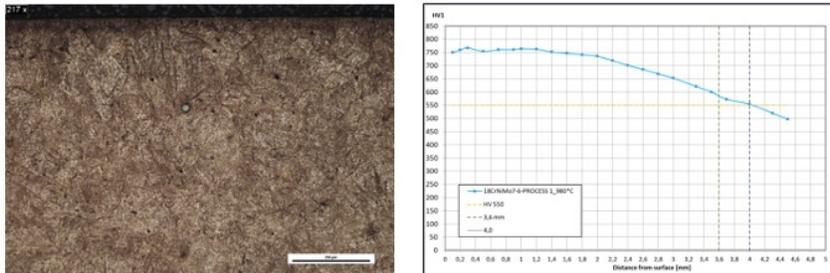
Cool and soak at 1,500 °F (820 °C)

Oil Quench

Temper at 360 °F (180 °C)

## CASE STUDY: Pit LPC Under the Microscope

- Results and Analysis

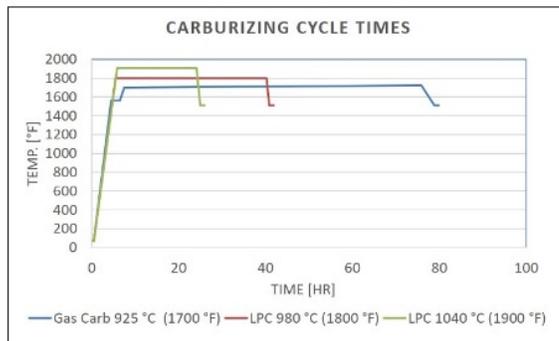


### Results and Analysis

All three carburizing processes combined with an oil quench and temper yield similar metallurgical results. The micrograph in Figure 14 illustrates the resulting structure which is martensite with approximately 10% retained austenite.

The accompanying hardness profile is shown in Figure 15. In this case, the surface hardness reached nearly 62 HRC on the surface and the effective case depth (ECD) was 0.157" (4 mm) as defined by 52.5 HRC or 550 HV while maintaining an appropriate ASTM grain size of 7. This profile was the result of the 1,800 °F (980 °C) LPC process [1].

## CASE STUDY: Pit LPC Under the Microscope



- Results and Analysis

To reach these results, the cycle durations shown in Figure 16 were required. It is important to note that gas carburizing conducted at 1,700 °F (925 °C) cycle requires nearly 80 hours to complete. Meanwhile, LPC conducted at 1,800 °F (980 °C) required only 42 hours to complete, which is almost a 50% reduction. A further increase in carburizing temperature to 1,900 °F (1040 °C) reduced the time to 26 hours which is a 68% reduction.

The reduced cycle time realized by the Pit Style-LPC decreases the utility use and virtually eliminates carbon dioxide and carbon monoxide emissions. The utility usage displayed in Table 4 shows an energy savings of 53% when LPC is used instead of atmosphere gas carburizing. Increasing the carburizing temperature while using LPC results in an increased savings of 61%. Also, it is important to note that LPC eliminates the need for natural gas and the corresponding CO<sub>2</sub> / CO emissions.

The corresponding cycle utility costs show that switching to LPC has the potential of a 47% savings. An increase in the LPC temperature yields an even higher savings of 54% [1].

## CASE STUDY: Pit LPC Under the Microscope

- Results and Analysis

Process Parameter	ATM PIT	PIT LPC	
Carburizing Temperature (°F)	1,700	1,800	1,900
Duration (hr.)	80	42	26
Energy use (kWh)	8,100	3,787	3,124
Nitrogen use (scf)	3,530	4,207	3,050
Acetylene (scf)	0	483	483
Natural gas (scf)	10,594	0	0
CO <sub>2</sub> emissions (metric tons)	0.59	=0	=0

Cost savings is not the only benefit of the Pit Style-LPC. The time savings also results in increased productivity when comparing with gas carburizing. Assuming a five (5) day operating week, the Pit Style LPC unit has the potential to be considerably more productive. At 1,800 °F (980 °C), the reduction in cycle time provides the potential to nearly double the possible number of annual cycles. Increasing the temperature to 1,900 °F (1040 °C) triples the annual number of cycles. Table 6 summarizes increase in productivity and the accompanying savings per cycle [1].

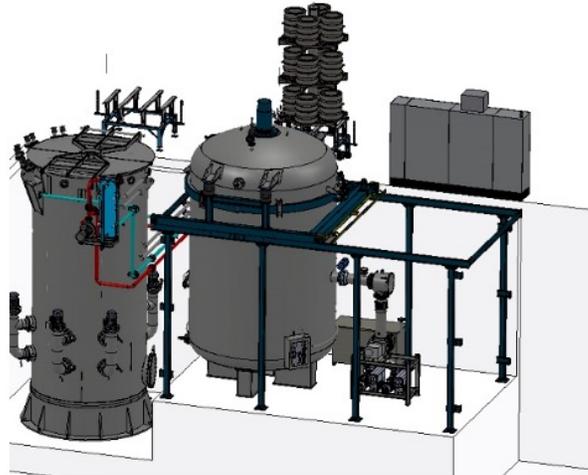
## CASE STUDY: Pit LPC Under the Microscope

Annual Processes	ATM PIT	PIT LPC
155		
	Carb. Temp: 1,700°F Total Cost: \$166,782 CO <sub>2</sub> Emissions: 91.5 metric tons	Carb. Temp: 1,800°F Total Cost: \$89,136 CO <sub>2</sub> Emissions: ≈0 metric tons
250		
	Carb. Temp: 1,700°F Total Cost: \$269,417 CO <sub>2</sub> Emissions: 147.5 metric tons	Carb. Temp: 1,900°F Total Cost: \$122,017 CO <sub>2</sub> Emissions: ≈0 metric tons

- Results and Analysis

To illustrate the potential savings, consider that the Pit Style LPC system is available for 6,500 hours annually. In order to match the 155 cycles available using the gas carburizing process, two atmosphere pit furnaces would be required. The total processing cost would amount to \$166,782 while the Pit-LPC costs would only be \$89,136. This is a total savings of \$77,646. Moving to the higher carburizing temperature requires a third atmosphere pit furnace to match the production of a single Pit-LPC. Meanwhile, the annual cost savings increases to \$147,400. Table 7 below summarizes the data behind this process savings [1].

## CASE STUDY: Pit LPC Under the Microscope



The Pit-Style LPC demonstrates many advantages when compared to atmosphere gas carburizing for case hardening large and heavy parts. The most notable advantage is the potential for reduced cycle time. Shorter cycles result in lower utility costs and increased productivity which reduces the period of return on investment. Along with this financial benefit comes the near elimination of CO / CO<sub>2</sub> emissions, increased safety of a vacuum furnace, along with the elimination of the flammable atmosphere and open flames. It is also important to note the potential for increased profit that comes with having fewer furnaces (less staff, operational costs, capital costs, etc.) that are more productive. These advantages can all be delivered by a furnace system that can be placed in the same location as an atmosphere pit furnace and accommodate the part geometries and weights that are expected from pit furnaces [1].

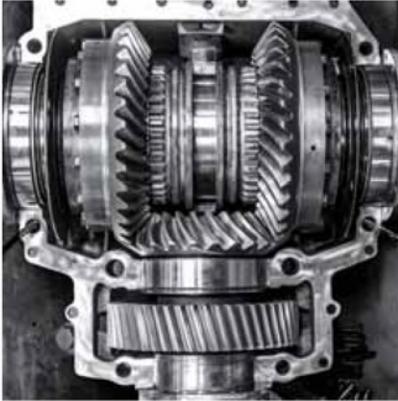
## CASE STUDY: Special Carburized Alloy Steel and LPC



Special carburized alloy steel is produced by Carpenter Technology Co. and intended specifically for use in heat-resistant drive units operating at temperatures exceeding the operating temperature of AISI 9310 steel.

Two additional alloys, molybdenum and copper distinguish it from commonly used steels for carburizing. Molybdenum increases the heat resistance and improves resistance to abrasion wear, whereas copper improves the resistance to shock load and lubrication properties.

## CASE STUDY: Special Carburized Alloy Steel and LPC



### **Thermal treatment of special carburized alloy steel:**

1. Carburizing at 870-930 C
2. Oil or gas quenching from 905-920 C.
3. Subzero treatment below -75C
4. Tempering at 150-290 C

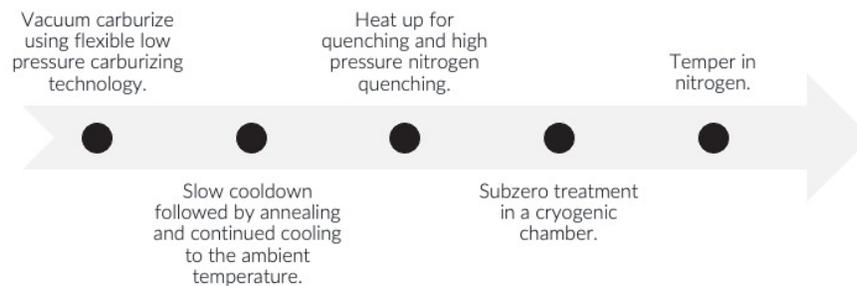
The thermal treatment of special carburized alloy steel involves the formation of a hardened case by carburizing and hardening (case hardening). The following are the phases of the process and the temperature parameters recommended by the producer.

1. Carburizing at 870-930 C
2. Oil or gas quenching from 905-920 C.
3. Subzero treatment below -75C
4. Tempering at 150-290C

## CASE STUDY: Special Carburized Alloy Steel and LPC

### Using LPC technology to create hardened special carburized alloy steel:

- Process sequence:



Analysis was done to see if a vacuum furnace with LPC carburizing system, enabled for high-pressure gas quenching, could create the special carburized alloy steel and bring any advantages to the process.

The process ran according to the following sequence:

1. Vacuum carburize using flexible low pressure carburizing technology.
2. Slow cooldown followed by annealing and continued cooling to the ambient temperature
3. Heat up for quenching and high pressure nitrogen quenching
4. Subzero treatment in a cryogenic chamber
5. Temper in nitrogen

## CASE STUDY: Special Carburized Alloy Steel and LPC

### Results and analysis:

- Vacuum carburizing by the low pressure carburizing method and high-pressure gas quenching (HPGQ) meets the requirements of the case-hardening process for special carburized alloy steel.
- The whole process can be conducted in a single chamber vacuum furnace in one working cycle.
- Vacuum carburizing processes are simulated with high accuracy on a dedicated simulator.



By analyzing the test and outcome, the following results were seen:

- Vacuum carburizing by the low pressure carburizing method and high-pressure gas quenching (HPGQ) meets the requirements of the case-hardening process for special carburized alloy steel.
- The whole process can be conducted in a single chamber vacuum furnace in one working cycle.
- Vacuum carburizing processes are simulated with high accuracy on a dedicated simulator.

## CASE STUDY: Special Carburized Alloy Steel and LPC

### Results and analysis:

- It is justified to apply an elevated carburizing temperature, which reduces the process duration greatly – for example, four times at a temperature of 980 C.
- The case hardness profile depends mainly on the carbon concentration profile, but it is also affected by the temperature of quenching, subzero treatment, and tempering.
- The temperature of quenching directly affects the core hardness (the higher the temperature the higher the hardness), which reaches 37-43 HRC at temperatures of 870-955 C.
- The temperature process of the subzero treatment affects the degree of the austenite transformation. The optimum temperature is -90 C.

It is justified to apply an elevated carburizing temperature, which reduces the process duration greatly – for example, four times at a temperature of 980 C.

The case hardness profile depends mainly on the carbon concentration profile, but it is also affected by the temperature of quenching, subzero treatment, and tempering.

The temperature of quenching directly affects the core hardness (the higher the temperature the higher the hardness), which reaches 37-43 HRC at temperatures of 870-955 C.

The temperature process of the subzero treatment affects the degree of the austenite transformation. The optimum temperature is -90 C.



## CASE STUDY: Special Carburized Alloy Steel and LPC

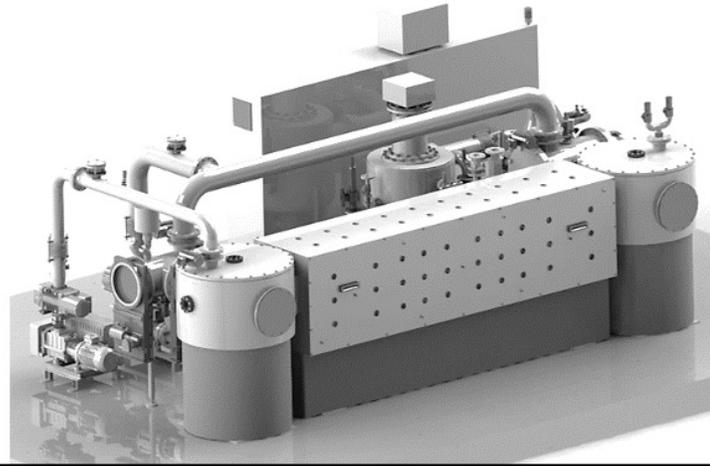
### **Results and analysis:**

- The tempering process affects surface hardness: the higher the temperature, the lower the hardness. A hardness of 65-63 HRC was achieved at temperatures of 175-290 C, which confirms the resistance of special carburized alloy steel to increased operational temperature.
- Special carburized alloy steel can be carburized to a surface carbon concentration level of approximately 1.0%, which makes it possible to obtain a flat profile of high hardness.
- The ratio of the case depth at a hardness of 60 HRC to the case depth at a hardness of 50 HRC directly depends on the surface carbon concentration and not on the case depth.

## LPC in Review

### Why LPC?

- The highest quality and uniformity of the process
- Excellent quality of the surface
- No surface oxidation (IGO)
- Reduction of the necessary media to the minimum = savings



Why LPC?

It offers...

The highest quality and uniformity of the process

Excellent quality of the surface

No surface oxidation (IGO)

Reduction of the necessary media to the minimum = savings



## LPC in Review

### **Why LPC?**

- Quick high-temperature process
- Minimum consumption of process gases
- Time savings as there is no need to prepare the process atmosphere
- Quick process initiation that does not require purging nor atmosphere conditioning as in atmosphere furnaces
- Safety: No flammable or explosive atmosphere
- Low heat emission and no pollution (CO & CO<sub>2</sub>)
- ECO friendly solution

Quick high-temperature process

Minimum consumption of process gases

Time savings as there is no need to prepare the process atmosphere

Quick process initiation that does not require purging nor atmosphere conditioning as in atmosphere furnaces

Safety: No flammable or explosive atmosphere

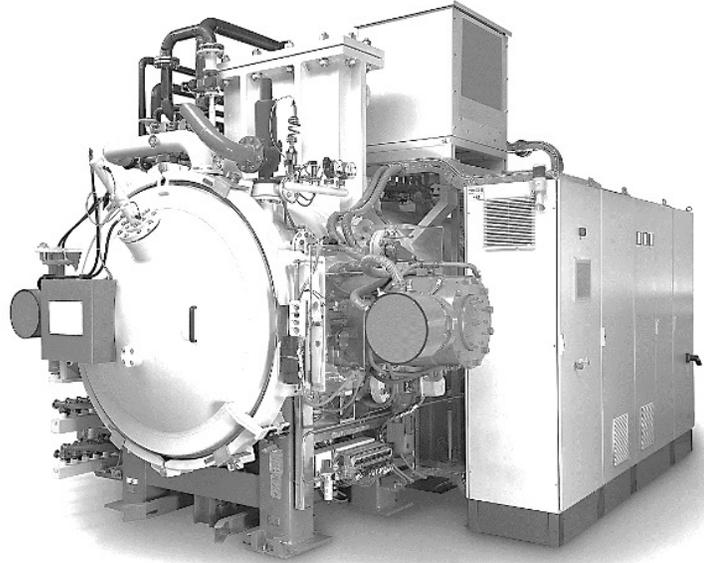
Low heat emission and no pollution (CO & CO<sub>2</sub>)

ECO friendly solution

## LPC in Review

### Why LPC?

- Carburizing costs & time reduction
- High quality (clean and bright) parts following heat treatment
- High reliability
- Very good process repeatability
- No load decarburization and oxidation
- Environmentally friendly – no CO<sub>2</sub> emissions



Carburizing costs & time reduction  
High quality (clean and bright) parts following heat treatment  
High reliability  
Very good process repeatability  
No load decarburization and oxidation  
Environmentally friendly – no CO<sub>2</sub> emission

## LPC in Review

### Why LPC?

- No open fire
- Cleanness of workplace
- No additional measuring equipment
- Full automation of the processes
- Visual computer control system and simulations



No open fire  
Cleanness of workplace  
No additional measuring equipment  
Full automation of the processes  
Visual computer control system and simulations



## Works Cited

(1)

**Vacuum Carburizing in a Pit Style Furnace: A 21<sup>st</sup> Century Solution to Large Component Case Hardening**

**Don Marteeny, P.E.**

*Vice President - Engineering*

*SECO/Vacuum Technologies, LLC*

*201 Arch St. 2<sup>nd</sup> Floor Meadville, PA 16335*

**Dr. Maciej Korecki**

*Vice President - Vacuum Business Segment*

*SECO/WARWICK S.A. 8 Sobieskiego Str. 66-200 Świebodzin, Poland*

**Dr. Agnieszka Brewka-Stanulewicz**

*Heat Treatment Process Engineer*

*SECO/WARWICK S.A. 8 Sobieskiego Str. 66-200 Świebodzin, Poland*

<https://www.asminternational.org/web/heat-treat>



## Works Cited

CASE STUDY PIT LPC

**Vacuum Carburizing in a Pit Style Furnace: A 21<sup>st</sup> Century Solution to Large Component Case Hardening**

**Don Marteeny, P.E.**

*Vice President - Engineering*

*SECO/Vacuum Technologies, LLC*

*201 Arch St. 2<sup>nd</sup> Floor Meadville, PA 16335*

**Dr. Maciej Korecki**

*Vice President - Vacuum Business Segment*

*SECO/WARWICK S.A. 8 Sobieskiego Str. 66-200 Świebodzin, Poland*

**Dr. Agnieszka Brewka-Stanulewicz**

*Heat Treatment Process Engineer*

*SECO/WARWICK S.A. 8 Sobieskiego Str. 66-200 Świebodzin, Poland*



## References

Herring, D.H. "The History of Vacuum Carburizing: 1968-Present." Process and Controls Training, 20-22 August 2019, SECO/WARWICK Corp., Meadville, PA.

Herring, D.H. *Vacuum Heat Treatment: Principles, Practices, and Applications*. Troy, MI, BNP Media II, 2012.



Thank You

***SECO/VACUUM***  
*We support your success.*

This concludes the continuing education unit on the **Understanding LPC: Fundamentals and Latest Advances in Low Pressure Carburizing Technology** course.

Please take the quiz to receive your credits.

Thank you for your interest in  
**SECO/VACUUM.**

For more information, visit  
<https://www.secovacusa.com>