Ipsen delivers

Producing Quality Parts in an Atmosphere Furnace: How to Optimize Your Quenching and Carburizing Processes

By Rene Alquicer, Manager – Atmosphere Products;
Aymeric Goldsteinas, Product Development Manager;
and Craig Moller, Chief Engineer

Producing Quality Parts in an Atmosphere Furnace: How to Optimize Your Quenching and Carburizing Processes

By Rene Alquicer, Manager – Atmosphere Products; Aymeric Goldsteinas, Product Development Manager; and Craig Moller, Chief Engineer
Ipsen, Cherry Valley, Illinois, United States

Introduction

Throughout the manufacturing process, heat treatment is consistently viewed as a critical step for adding value to the parts produced. A part expensively manufactured by melting, hot rolling or forging, annealing, rough machining, teeth cutting and grinding is essentially useless and of little to no value without heat treatment. In addition, without reliable and repeatable heat treatment, it is impossible to achieve competitive overall manufacturing costs.

Amazingly, the cost for a manufacturing step that adds such a high value is only a fraction of the total production costs – generally in the range of no more than 5%. This percentage, however, increases to roughly 15% of the costs per part if all further post-treatment process steps inherent with, or caused by, heat treatment – such as cleaning, blasting, straightening and/or grinding – are taken into account. Therefore, a noticeable reduction of the manufacturing costs is only possible by minimizing the distortion of parts. For this, all the influencing parameters like steel melting, forming of the parts, uniformity of microstructure and hardenability, as well as the natural factors of the heat treatment process – positioning of the parts in the load, uniformity of heating, carburizing and heat extraction during quenching – need to be analyzed and optimized if one is to continually produce quality parts in batch atmosphere furnaces.

When producing quality parts, we are primarily concerned with properly utilizing the carburizing and quenching processes and applicable modern technology. From optimizing controls and quenching systems to the benefits of establishing temperature and gassing uniformity, here are some tips highlighting how to make the most of your processes and atmosphere furnace.

Carburizing – The Importance of Uniformity

While there are currently two industrial carburizing processes – gas carburizing in atmosphere furnaces and low-pressure carburizing in vacuum furnaces – both have the same aim: to carburize all parts in a load uniformly, to the same surface carbon (C) content and to the same case depth.

Atmosphere carburizing runs a series of different process steps. Knowledge of these steps is necessary for achieving repeatable work and uniform carburizing:

1. **Gas reactions:** generation of the carburizing gas components in the atmosphere
2. **Convective gassing:** transport of the carbon-containing molecules in the gaseous phase to the component
3. **Diffusion transport:** transport of the carbon-containing molecules through the boundary layer (v=0) at the component surface
4. **Dissociation and adsorption:** dissociation of the molecules at the component surface
5. **Absorption:** taking up of the carbon by the component surface
6. **Diffusion:** transport of the carbon into the component

Overall, the gas reactions which take place in the carburizing atmosphere are many and varied. Taking into consideration the six process steps listed above, ideal carburizing conditions exist if temperature and gassing uniformity, flow over the components and fast reaction kinetics occur evenly throughout the treatment chamber. By achieving ideal conditions in these areas, one can positively influence the quality of components produced.

How to Ensure High-Quality Parts: Temperature Uniformity

A uniform temperature is one of the first, and most essential, steps for ensuring parts emerge with an ideal carburizing depth – and thus higher quality. In efficient batch atmosphere furnaces, such as the Ipsen ATLAS, temperature uniformity of at least ±13 ºF (±7 ºC) is maintained in the heat chamber. Upon completion of the heating phases, all components in the austenitic phase are at the same temperature.

Efficient burners – like Ipsen's Recon® III Burners – can enhance the heating of batch furnaces. These burners are single-ended recuperative tubes (SERT) fitted with special

ceramic inner tubes. The burners increase thermal efficiency up to 75% simply by recovering the heat from the exhaust gases and reducing time to recovery of the hot zone temperature. Distinguished by low noise levels, high durability, low maintenance and easy installation, these modern burners provide ideal heating while optimizing gas consumption. Reliability comes from excellent furnace designs. One example of this is, if one of the burners is down in the middle of a cycle, the other burners are adaptive and will compensate so that excellent uniformity can still be achieved throughout.

However, it's important to realize that achievement of temperature uniformity is not possible without improved gas flow over the components. You must have a well-planned circulation system to achieve excellent flow around components and, thus, maintain temperature uniformity.

Atmosphere Q&A:
A Firsthand Look at Ipsen's ATLAS System

Q: Ipsen's newest atmosphere furnace is the ATLAS single-chain model. What type of atmosphere system is the ATLAS, and what does that mean for users?
A: Ipsen's single-chain ATLAS is an integral quench batch system (Fig. 1). This single-chain, in-out-style furnace has a load size of 36" x 48" x 38" (W x L x H) and features all of the ATLAS system's latest technological advantages.

Fig. 1: The ATLAS single-chain, integral quench batch atmosphere system

The single-chain model is configured for maximum compatibility and utilizes the same push-pull chain loader as the industry standard, allowing it to integrate into existing lines for any brand of atmosphere furnace with ease.*

When it comes to the market for atmosphere heat-treating systems, Ipsen has always been a strong leader with one of the largest installed bases of atmosphere furnaces in the United States – several thousand since we were founded in 1948. In fact, our founder, Harold Ipsen, was a pioneer in the development of integral-quench, batch-atmosphere furnace technology.

Although we have an established atmosphere base, Ipsen believes that innovation drives excellence. For Ipsen, a key part of innovating is listening to the specific needs and challenges of our customers and then providing ideal solutions that meet those needs. As we focus on the continuous improvement of our atmosphere products, we have dedicated significant resources toward gathering input from our customers and heavily researching industry needs.

This focus and research – as well as our experienced team of engineers working on research and development – allow us to tailor our products and services so we can provide our customers with optimum equipment they can trust and rely on for full-scale solutions.

Q: Where is the ATLAS single-chain model manufactured for the North American market?
A: The ATLAS single-chain model is manufactured in the United States at our facility in Cherry Valley, Illinois. Our extensive U.S. Field Service and Aftermarket Support network provides atmosphere furnace support, including parts, service, retrofits, training and more.

Q: What are some of the advantages of manufacturing the ATLAS single-chain model in the United States?
A: One of the main advantages is providing our customers with prompt, timely service and support. When customers are deciding on what equipment to invest in, we've found one of the factors they consider is the location of the manufacturing and service network facilities.

With locations across the United Sates, we're able to deliver spare parts, perform maintenance and more, all while minimizing companies' downtime. In addition, our comprehensive on-hand stock inventories comprise more than 2,000 items, ensuring our customers quickly receive the required parts and components needed to maintain their heat-treating equipment.

Q: Does Ipsen offer entire atmosphere systems?
A: Yes, Ipsen's batch furnace systems are comprised of several components – sealed-quench furnaces, temper furnaces, washers and loaders. These complete atmosphere systems provide users with a high level of flexibility as they can execute different thermal processes in each sealed-quench furnace, as well as expand the system for larger production needs and future increases in demand.

Q: What are a few of the ATLAS system's unique features?
A: If I had to sum it up, I would say the ATLAS system's most unique core features include:

- Ability to integrate into existing atmosphere furnace lines (any brand)*
- Intelligent controls with predictive process capabilities – Carb-o-Prof®
- Compact footprint
- Ease of maintenance, thanks to a cartridge-design heat fan assembly, shelf-mounted quench oil heaters and oil circulation pump, safety catwalks and more
- Efficient heating combustion system, which provides energy and cost savings
- Variable-speed quench agitation, allowing users to achieve and maintain better quenching control
- Uniform quenching, resulting in minimized distortion and high part quality

Q: How do you consistently get good results out of your equipment?
A: Well, first it's important to understand there are several factors that contribute to high-quality parts – the biggest is temperature uniformity. This is why we engineered the ATLAS system to efficiently maintain:

- Temperature uniformity
- Atmosphere uniformity
- Uniform quenching
- Precise and consistent control of the carbon potential

Q: You mention that the ATLAS furnace provides uniform quenching. Can you expand on this?
A: Achieving uniform quenching can only be accomplished with a sufficient and uniform flow of oil around the part. To accomplish this, you need an efficient quench system design.

As such, the ATLAS features TurboQuench™, a modern oil-quenching system with an agitation system that produces a uniform and adjustable flow of oil throughout the load. By using high oil flow velocity, users can achieve a uniform cooling

rate on the part's entire surface area, resulting in uniform surface and core hardness with low distortion.

Q: In summary, when working with batch atmosphere furnace systems – such as Ipsen's ATLAS – what are some of the most essential things to consider?
A: When working with batch atmosphere furnaces – especially when you are carburizing – it's essential that the system is capable of:

- Achieving tight temperature uniformity
- Maintaining consistent carbon potential
- Quenching uniformly
- Controlling the quench rate

Why is this important? Because having these capabilities allows you to be more competitive by consistently and economically producing high-quality parts with reduced distortion.

**Compatible with most single-chain, in-out-style atmosphere furnace lines*

How to Ensure High-Quality Parts: Gassing Uniformity
The positive convective properties, which result in excellent temperature uniformity within the load area, also result in improved heat transfer to the load and homogenous process atmosphere. Figure 2 portrays how the combination of minimum temperature deviation within the load area and the homogenous process atmosphere results in minimized case depth deviations throughout the load.

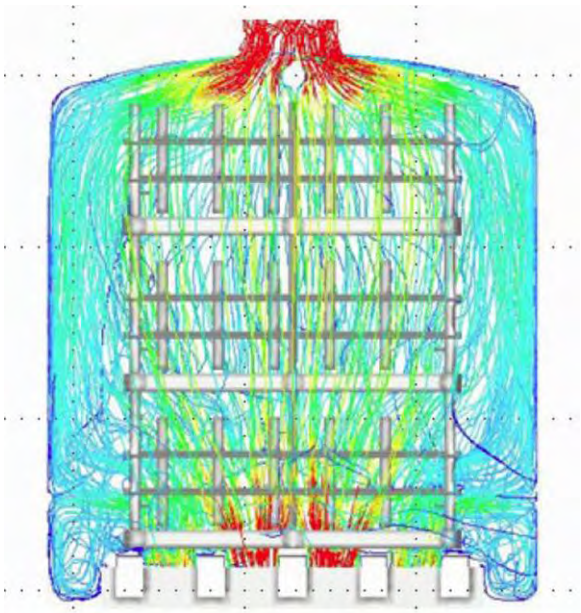

Fig. 2: Representation of the fluid flow lines in a treatment chamber

Continuous introduction of the carrier gas and controlled additions of the enriching gas result in a furnace atmosphere capable of producing carburized parts with the specified percent of surface Carbon and to a specified case depth with highly repeatable results, as shown in Figure 3.

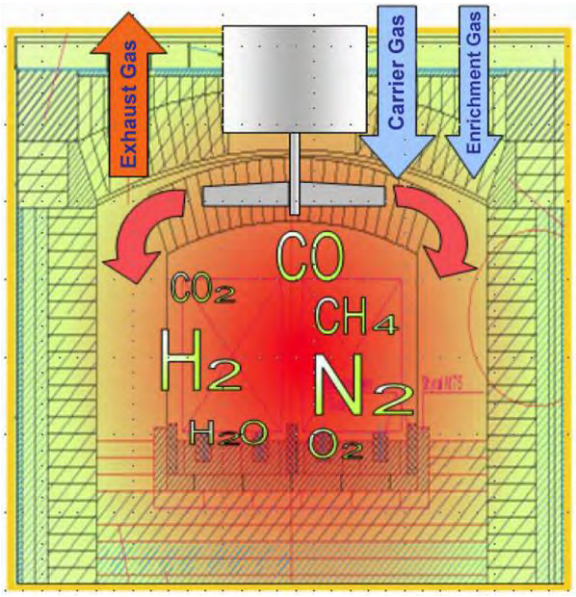

Fig. 3: A furnace atmosphere during gas carburizing

Intuitive control software, such as Ipsen's Carb-o-Prof® system, can assist in maintaining balance by regulating, documenting and archiving the carburizing processes in atmosphere furnaces. No matter the case – if your power goes out or some other unforeseen event occurs – the software is able to adapt the process to the changing circumstances, preventing the potential waste of parts and resources. Even before actually processing the load, users are able to generate a potential recipe and immediately

review the process results using the advanced simulation software.

Specifically, the software monitors and controls uniformity of the C-level within the atmosphere; which, through supervision, maintains a tolerance of ±0.05% C for the workpiece surface carbon content. This consistency of the atmosphere's carburizing effect results in uniform carburizing of the surface layer, as shown in the example of a gear wheel in Figure 4.

When striving towards uniform carburizing, it is important to remember that temperature and gassing uniformities are interrelated – it is difficult to meet one parameter without influencing the other.

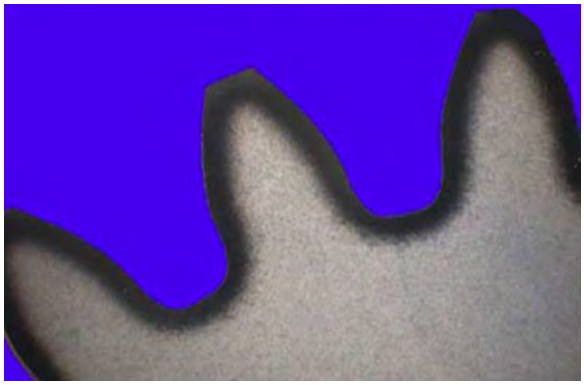

Fig. 4: Uniform surface carburizing of a gear wheel

Carb-o-Prof®– Boosting Efficiency with Intelligent Controls

Ipsen's Carb-o-Prof software combines more than six decades of knowledge and expertise in a single controls system, and it is specially designed for the computation and execution of the complete carburizing and quenching cycles, as well as other heat treatment processes. Overall, it provides the flexibility needed to measure and analyze your equipment and processes with ease. You can then use this analysis to refine and adjust the settings and parameters of your equipment to enhance your process, thus improving the quality of your parts.

This unique, reliable software consists of flexible controls and straightforward user prompts and color menus – making for a user-friendly experience. Other features include an extensive recipe database, an adaptive C-profile control and a time- and cost-saving simulation function.

Recipe Database
Programmed with hundreds of available recipes, the database allows the most important recipe information to be registered via a quick, simple input. Faulty inputs are prevented by appropriately limiting the input range, thus maintaining a safe operation and avoiding excessive consumption. As a result, recipes are generated in an easy, consistent manner that focuses on the carburizing/hardness results and prevents input errors.

Simulation with C-Profile Optimization
An outstanding, standard feature of Carb-o-Prof is its simulation function. It computes the materials' expected carbon profile according to entered parameters and displays the results as a table and straightforward graph – as demonstrated by Figure 5.

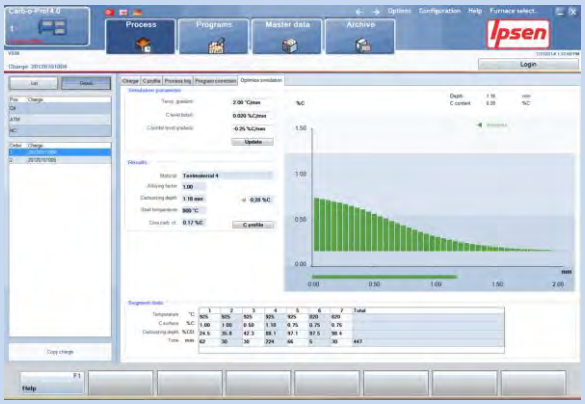

Fig. 5: Example of a simulated test run conducted using Carb-o-Prof software

The profile can then be re-evaluated and parameters adjusted, if necessary. Overall, this gives users the ability to review the process results for their specific load immediately after generating the potential recipe – all without having to do the actual run. Due to the fact that no test load needs to be run beforehand, no valuable parts, time or resources need to be wasted.

C-Profile Control
Using pre-specified target parameters, such as surface carbon content, carburizing depth and/or core carbon content, Carb-o-Prof is able to define a target carbon-content curve in the shape of a smooth S-form. As a result, parts within the same load are consistent in both case depth and hardness, and this outstanding performance is consistently repeated load after load.

Quenching – The Importance of Oil Flow

Older quench systems for batch atmosphere furnaces used to possess little flexibility with respect to varying the quench intensity. Experience shows there is significant potential for optimizing, as well as producing, a uniform quench in oil. The implementation of these techniques has produced a more uniform hardening of parts – especially of gear components – with an improved microstructure and reduced distortion. Today's requests of adapting the quenching intensity of quench systems to the needs of different components – specifically hardenability and minimization of distortion – have also led to the increased production of quality components.

Modern oil quenching systems, like Ipsen's SuperQuench® and TurboQuench™, have an all-encompassing agitation system, allowing them to produce a uniform oil flow through the load section, as well as utilize an adjustable oil flow speed. In addition, by utilizing the agitators' timing control, their cooling curve can reach results closer to the ideal cooling curve, as seen in Figure 6. This feature increases the efficiency and flexibility of oil quench systems and makes hardening of low-alloyed materials and thicker cross-sections possible.

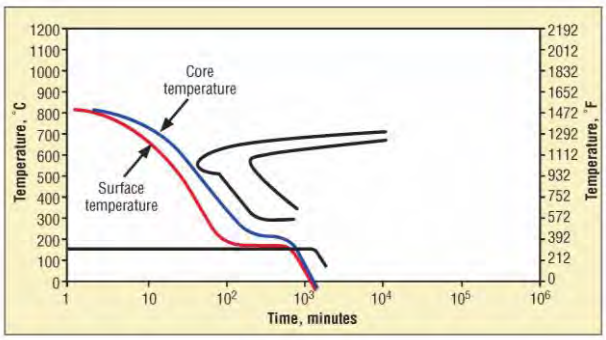

Fig. 6: Representation of an ideal cooling curve with a high cooling rate to start and a cooling rate reduction when entering the martensitic phase

In addition, the realization of complex quench cycles is easily done with the proper control software. A quench cycle is established within the software by assessing the section size, the type of material, load density, temperature and the type of quench oil.

How to Achieve Ideal Quench Speed and Heat Extraction
The goal of a uniform heat extraction over the whole surface part can only be reached with an equal flow of oil around the entire part. While this situation is possible with simple parts, it is very difficult with complex part geometries, yet still achievable with an efficient quench system.

It is important to be aware of the vapor phase, also commonly known as the Leidenfrost effect. This phenomenon occurs when a liquid – which is in near contact with a mass significantly hotter than the liquid's boiling point – forms an insulating vapor film that keeps the liquid from boiling rapidly. Then, as the vapor film randomly breaks down, the nucleate boiling phase starts and is characterized by a high cooling rate. The final stage is the convection phase.

One way to prevent the difficulties associated with the vapor phase is by using non-evaporable media like salt or gas. Their cooling rate in the upper temperature region, however, is usually not sufficient for low-alloyed or carbon steels. Therefore, the objective must be to optimize the oil quenching in such a way that it reproduces an ideal cooling curve.

Assuming the usage of a high-performance quench oil – as is normal in sealed quench furnaces today – a high oil flow velocity best achieves a high, uniform cooling rate on the entire surface area of a part. This speeds up the breakdown of the vapor film in areas of less flow, producing a more uniform, faster quench.

Higher oil velocities considerably improve the uniformity of heat extraction. Depending on the thickness of the part and the hardenability of the respective steel, the influence of the flow velocity can also result in further quality improvement of the part.

How to Reduce Distortion
The goals for a distortion-optimized quenching can generally be defined as follows:

- Uniform heat extraction over the whole surface of the part
- Uniform heat extraction on every part within one load
- Material- and part-adapted timing to control the quench intensity

These goals are realized throughout the quenching cycle. The first part of the quenching cycle uses a maximum oil flow so that a quick vapor film breakdown occurs and a high heat extraction is realized in the nucleate boiling phase – all of which prevents the production of ferrite and perlite.

The second part of the quenching cycle reduces the cooling rates to allow temperature homogenization between the surface and core before martensitic transformation starts. This equalizes thermal and transformational stresses; therefore, producing less distortion.

As Figure 7 demonstrates, these modern, innovative systems allow you to achieve optimized performance and produce quality components as compared to a conventional oil bath.

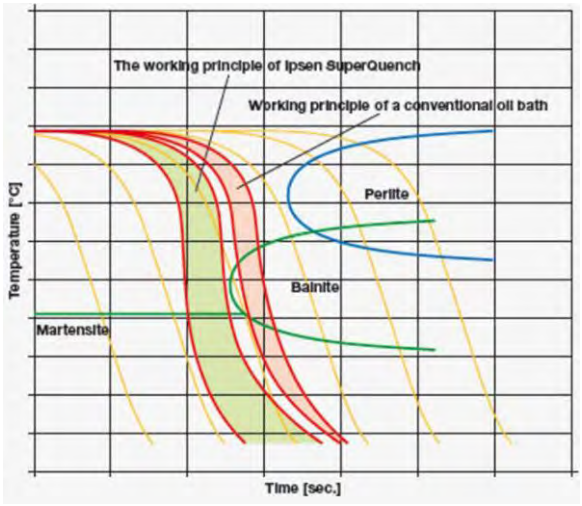

Fig. 7: Comparison of the SuperQuench® system's working principle (left) to that of a conventional oil bath (right)

TurboQuench™ – Achieving Precision Load after Load

Regardless of whether you're quenching bulk or very dense loads, Ipsen's TurboQuench™ system tackles even the most challenging alloy by reducing the spread of hardness values, thus maximizing the parts produced per load. With a vertical oil pump, four VFD-controlled agitators, eight oil heaters and an optimized plenum and baffle design, the TurboQuench system produces a uniform and adjustable flow of oil throughout the load. These comprehensive features ensure a reduced footprint, ease of maintenance, increased oil bath control and the ability to integrate into existing pits while maintaining the proper load to oil ratio.

Overall, the TurboQuench system allows the entire load to be reliably, uniformly and quickly quenched – thus resulting in optimum quenching and minimal distortion. Paired with the efficient heating system of the ATLAS integral quench batch furnace, the powerful but flexible TurboQuench system ensures you achieve precision, load after load, even for the most varied and demanding materials.

Conclusion

When carburizing/through-hardening and quenching parts in a batch atmosphere furnace, it is essential to achieve uniformity of temperature and gassing, optimize the flow over components and aim for ideal quench speeds and heat extraction by utilizing various high-performance systems. All of which allows you to produce high-quality parts with reduced distortion, as well as achieve competitive, overall manufacturing costs via heat treatment.

In addition, through the use of modern technology – such as Ipsen's Carb-o-Prof controls, SuperQuench and TurboQuench systems and Recon III Burners – one can achieve ideal end results when using the carburizing/through-hardening or quenching processes. In the end, the enhanced design and control of such technologies allows you to positively impact your processes, as well as utilize the tips provided for producing quality parts.

For more information contact ATLAS@IpsenUSA.com or 1-800-727-7625, or visit www.IpsenUSA.com/ATLAS.