Swedish Suppliers of Heat Treatment Equipment

Värmebehandlingskonferensen, 4 – 5 maj 2022 på Aronsborg Konferens i Bålsta

Controlled Carbonitriding Furnace Modifications and Benefits

4th May 2022

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Outline

- Definition
- Motivation
- Furnaces
- Process Controll
- Examples
- Conclusion

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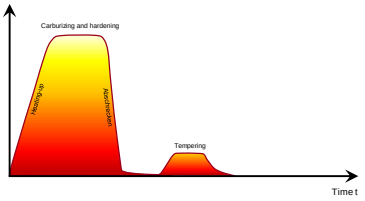
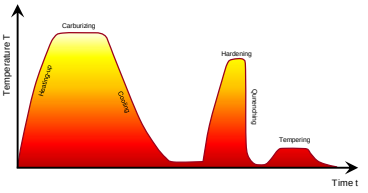
Terms and Definition

- **Carburizing** C
  Enrichment of the surface layer of a workpiece with carbon by thermochemical treatment

- **Carbonitriding** C + N
  Enrichment of the surface layer of a workpiece with carbon and nitrogen by thermochemical treatment

- **Case hardening**
  Carburizing or carbonitriding followed by quenching:





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Motivation

Carbonitriding- Generell Advantages

- Increased hardenability (of the case layer)
  - Reduced troostite area
  - Slightly increased CHD
- Higher thermal resistance
- Increased retained austenite content
- Higher fatigue strength
- Reduced distortion?

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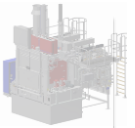
Furnace Technology for Gas Carbonitriding



Quantity of ammonia to be added during carbonitriding

Ammonia dissociation is highly dependent on the furnace temperature used. The higher this is, the faster the ammonia decomposes in the furnace atmosphere without it being able to produce a nitriding effect.
The higher the treatment temperature, the more ammonia has to be used in order to achieve a comparable nitriding effect.

For a surface nitrogen content of approx. 0.40% N is required for an average charge surface

- at approx. 850°C – 880°C an ammonia amount of approx. 5-8 % of the total gasing.
- at approx. 880°C – 900°C an ammonia amount of approx. 8-10 % of the total gasing.
- at approx. 900°C – 920°C an ammonia amount of approx. 10-12 % of the total gasing.
- at approx. 1000°C an ammonia amount of approx. 25-30 % of the total gasing.

In the case of batches with a very large surface, this quantity can increase further.

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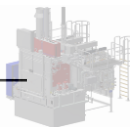
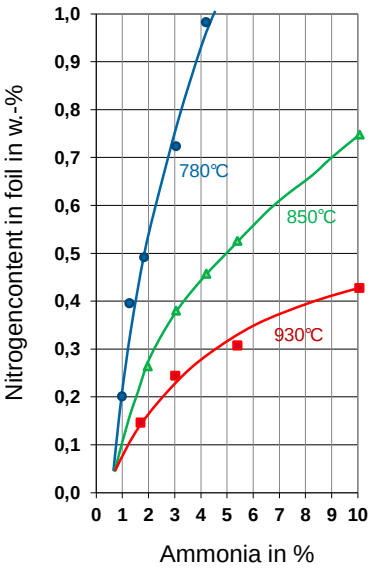
Ammonia content in the furnace during carbonitriding





Acc. R. Chatterjee

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Furnaces

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Key Processes Characteristics

A2	Gas – carbonitriding

Furnace Types	(R)TQ, ATLAS, Pusher-type furnace	ATM < 750° / VAC > 750°

Gear shaft

Typically used materials

- Case hardening steels 16MnCr5, C15
- Ball and roller bearing steels 100Cr6
- Free-cutting steels 11SMnPb30
- PM steels and cast iron

ATLAS

Process profile

• Temperature range	850 – 900°C
• Process time	typ. 2 – 120 h
• Pressure range	excess pressure, 1,5 – 2,5 mbar
• Quenching	Oil-Quench, High-Pressure Gas-Quench
• Used gases	endothermic gas, N_2 / Methanol (C_3H_8), hydrocarbons (CH_4, C_3H_8), NH_3 (for carbonitriding)

Users / Industries

- Automotive and machine engineering
- Tools
- Commercial heat treaters

Benefits of the process

- Improved fatigue strength and wear resistance
- Increased surface hardness and hardenability

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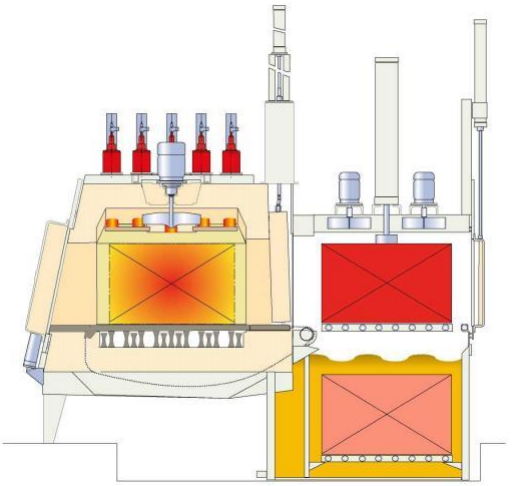
Design of the Ipsen batch furnace (TQF)



- Furnace housing
- Brick work
- Heating system
- Gas circulation system
- Quenching system
- Transport system

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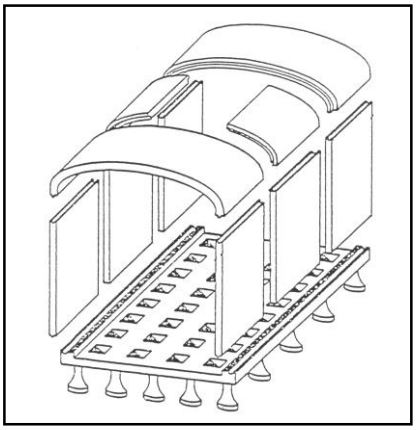
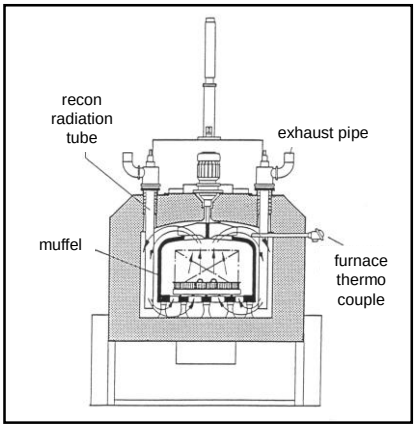
Gas Guiding System with Muffle





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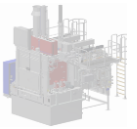
Heating chamber with inner door



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Process control

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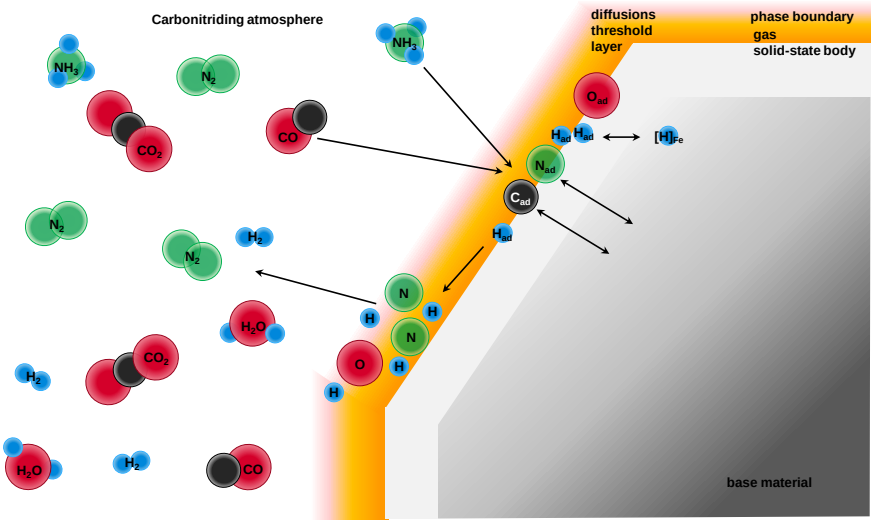
Reactions during Carbonitriding



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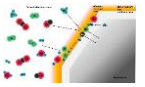
Different gasing systems



Generation of a furnace atmosphere

indirect

endogas
- high gassing ratio
- suitable temperature range
- constant CO-content

Recirculation
- lowest gassing ratio
- suitable temperature range
- Recirculation principle

direct

nitrogen-methanol
- high gassing ratio
- suitable temperature range
- variable CO- content

hydrocarbon-air
- low gassing ratio
- restricted temperature range
- atmosphere is not in chemical balance

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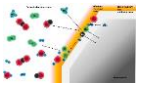
Gas Composition of „Endogas“



Reaction of gaseous carbohydrates with Air

Natural gas plus Air:

$CH_4 + 2{,}5\ (0{,}2\ O_2 + 0{,}8\ N_2) \rightarrow CO + 2\ H_2 + 2\ N_2$

ca. 20 Vol% — ca. 40 Vol% — ca. 40 Vol%

Propane plus Air:

$C_3H_8 + 7{,}5\ (0{,}2\ O_2 + 0{,}8\ N_2) \rightarrow 3\ CO + 4\ H_2 + 6\ N_2$

ca. 23,8 Vol% — ca. 32,2 Vol% — ca. 44 Vol%

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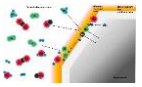
Different possibilities of Carbon potential control



Chemical balance reactions	Measurement system
$CO + H_2 \rightleftharpoons [C] + H_2O$	**Dew point measurement** • very fast approach of chemical balance
$2\ CO \rightleftharpoons [C] + CO_2$	**CO_2- Analyses** • slow approach of chemical balance • good possibilities of measurement • often used as a redundant control system
$CO \rightleftharpoons [C] + O$	**Oxygen partial pressure** • very fast approach of chemical balance

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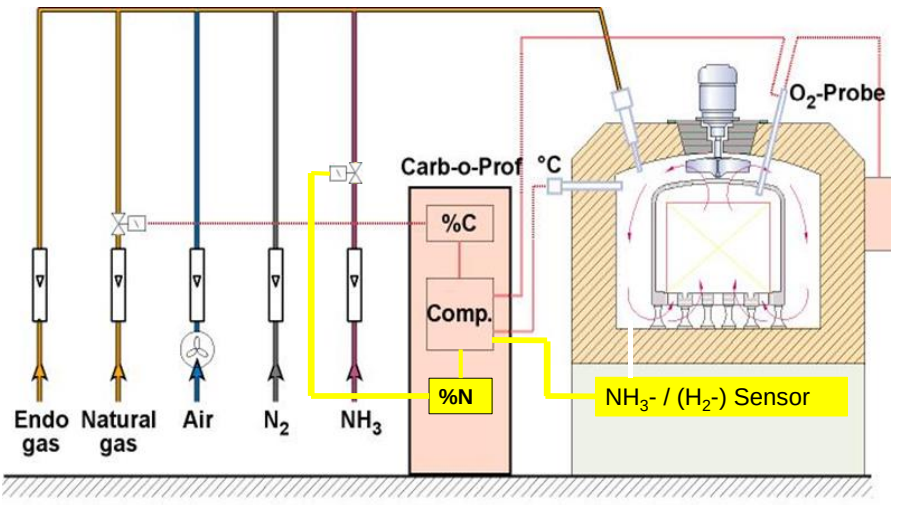
Gas Panel for Gas Carbonitriding with „Endogas“



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Gas Compositions for „Nitrogen / Methanol“

Injection of **Methanol** and **Nitrogen** into the furnace:

Pure Methanol:

$$CH_3OH \rightarrow CO + 2\,H_2$$

ca. 33 Vol% ca. 66 Vol%

And with 40% N_2:

$$CH_3OH + 2\,N_2 \rightarrow CO + 2\,H_2 + 2\,N_2$$

ca. 20 Vol% ca. 40 Vol% ca. 40 Vol%

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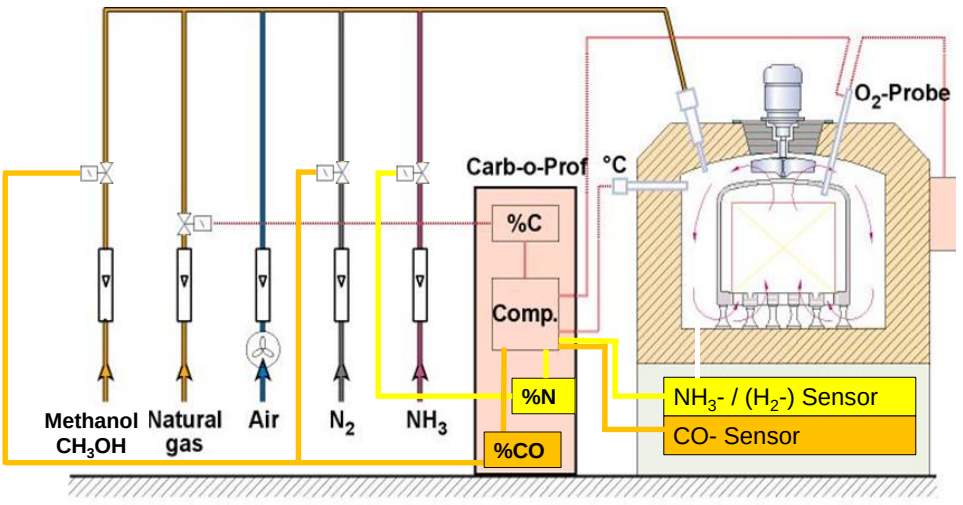
Gas Panel for Gas Carbonitriding with Nitrogen / Methanol



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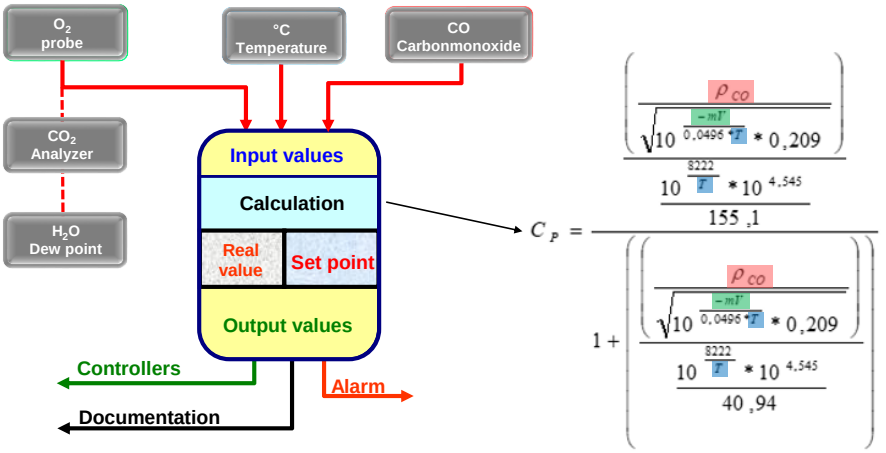
Carbon-Potential calculation



$$C_P = \frac{\left(\frac{\rho_{CO}}{\sqrt{10^{\frac{-mT}{0,0496 \cdot T}} * 0,209}}\right)}{\frac{10^{\frac{8222}{T}} * 10^{4,545}}{155,1}}$$

$$1 + \left(\frac{\left(\frac{\rho_{CO}}{\sqrt{10^{\frac{-mT}{0,0496 \cdot T}} * 0,209}}\right)}{\frac{10^{\frac{8222}{T}} * 10^{4,545}}{40,94}}\right)$$

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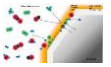
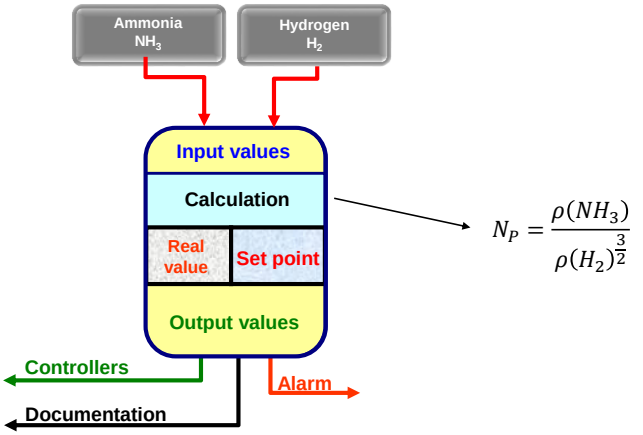
Nitrogen-Potential calculation





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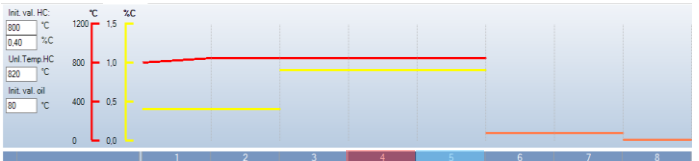
Programs for controlled (gas-) carbonitriding processes



	1	2	3	4	5	6	7	8
Segment status	Heating	Holding	Holding	Holding	Holding	Oil	Oil	Atm.
Time min	1	20	45	30	210	10	10	10
Digital outputs	-	-	-	-	-	-	-	-
Heating chamber								
Temperature °C	850	850 >				80	80	80
CL status	ON	ON	ON	ON	ON			
C content surf. %C	0,4	0,4	0,9	0,9	0,9			
mV controlling mV	--------	--------	--------	--------	--------			
CO %	20,0	20,0	20,0	20,0	20,0			
NH3 nl/h	OFF	OFF	OFF	1330,0	ON			
Carburizing up to CD								
Quenching chamber								
Oil agitation						ON	ON	ON
Oil agitation (fast speed)						ON	OFF	
Direction of oil agitation						upward	upward	
Oil oscillation						--------	--------	
ATM agitation						OFF	OFF	OFF
Flow								
N Pegel %	0,00	0,00	0,00	0,00	0,70			

Conditioning segment with fixed ammonia flow rate

Controlled segment with set point for the N-potential

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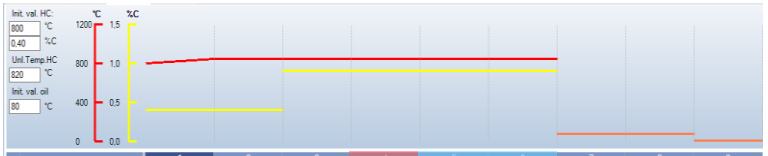
Controlled (gas-) carbonitriding processes with CO-Control



	1	2	3	4	5	6	7	8	9
Segment status	Heating	Holding	Holding	Holding	Holding	Holding	Oil	Oil	Atm.
Time min	1	20	45	30	60	150	10	10	10
Digital outputs	-	-	-	-	-	-	-	-	-
Heating chamber									
Temperature °C	850	850 >					80	80	80
CL status	ON	ON	ON	ON	ON	ON			
C content surf. %C	0,4	0,4	0,9	0,9	0,9	0,9			
mV controlling mV	-------	-------	-------	-------	-------	-------			
CO %	20,0	20,0	23,0	23,0	23,0	17,0			
NH3 nl/h	OFF	OFF	OFF	1330,0	ON	ON			
Carburizing up to CD									
Quenching chamber									
Oil agitation							ON	ON	ON
Oil agitation (fast speed)							ON	OFF	
Direction of oil agitation							upward	upward	
Oil oscillation							-------	-------	
ATM agitation							OFF	OFF	OFF
Flow									
N Pegel %	0,00	0,00	0,00	0,00	0,70	0,70			

Conditioning segment with fixed ammonia flow rate

Controlled segments with set point for the N-potential

Segments with varying set points for the CO - content

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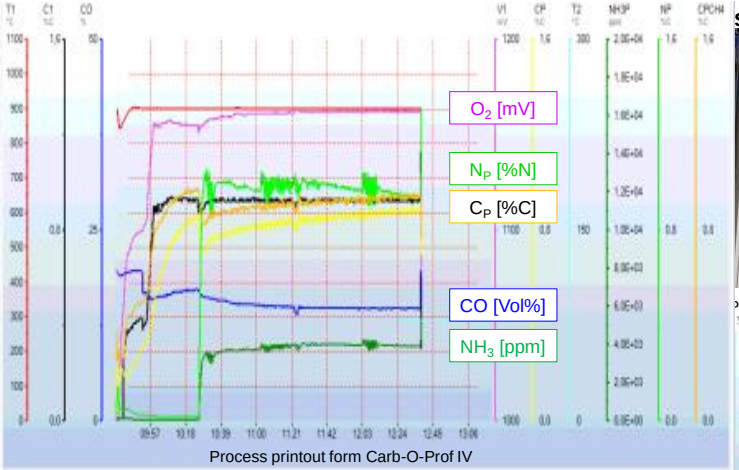
Controlled (Gas-) Carbonitriding
Furnace technology and processes

Heat t **sen,**

Carbur



Process printout form Carb-O-Prof IV

CH_4 (0 … 10 Vol%)
NH_3 (0 … 5000 ppm)

Process printout form Carb-O-Prof IV

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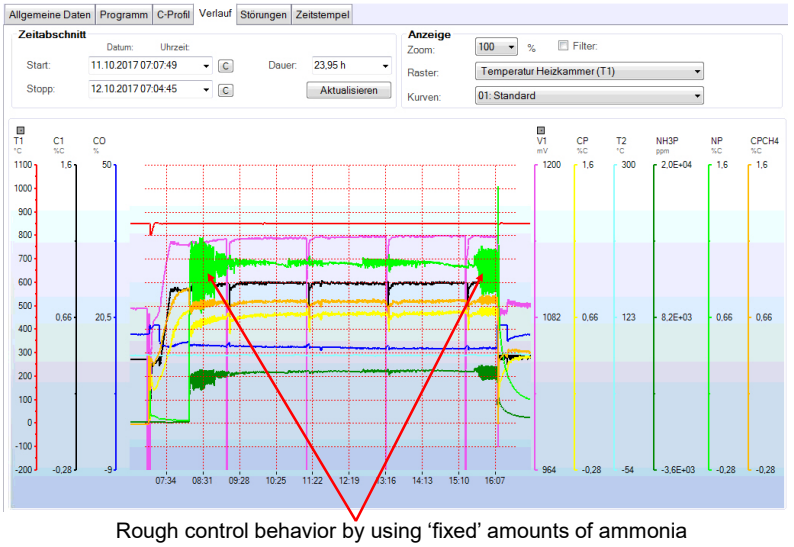
Controlled Carbonitriding with On/Off Flow Control



Rough control behavior by using ‘fixed’ amounts of ammonia

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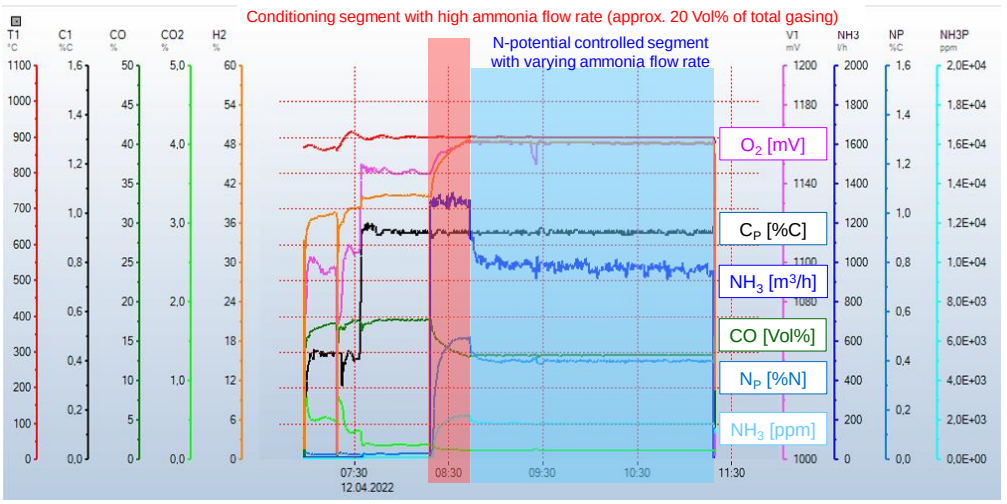
Controlled (Gas-) Carbonitriding with MFC



process printout by using MFC controlled amounts of ammonia

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Examples

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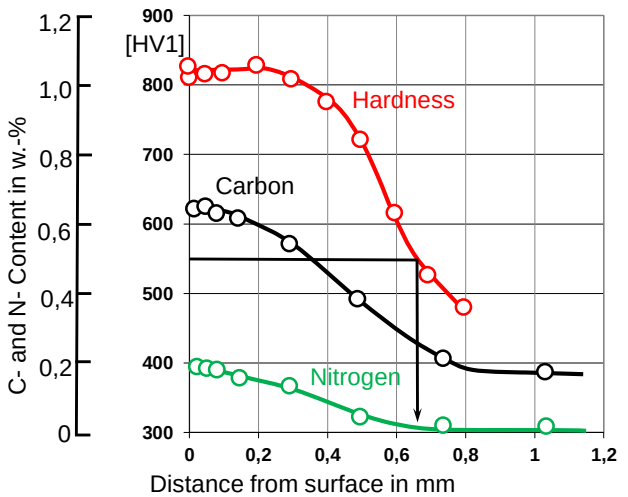
Potential Carbonitriding Result



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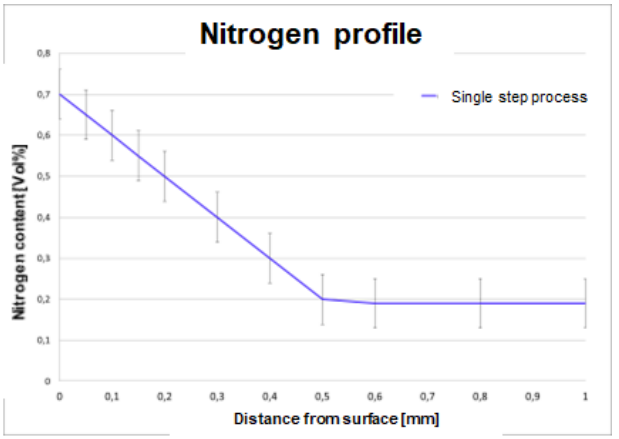
Advantages of Controlled (Gas-) Carbonitriding 1/3

Advantage 1: By controlling the N level, the process is independent of the furnace temperature and the surface of the load and delivers **the same repeatable results with the same program** (and of course the same component).



Due to the strong dependence on temperature and surface (load and active furnace surface) of the ammonia (NH_3) decomposition, a controlled carbonitriding process offers several advantages compared to a process with fixed gassing quantities:

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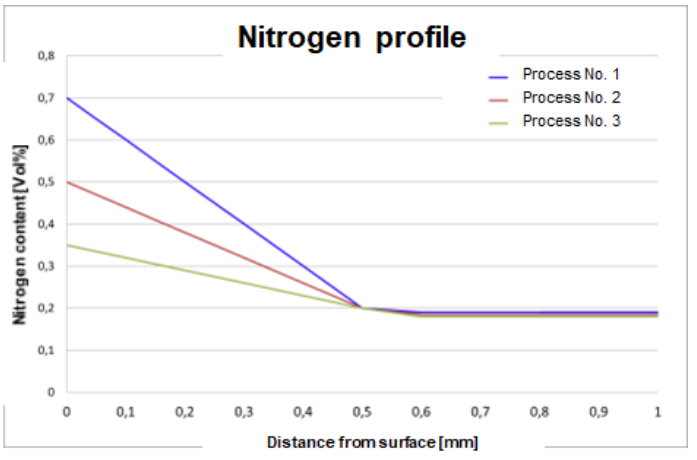
Advantages of Controlled (Gas-) Carbonitriding 2/3

Advantage 2: By controlling the N level, **defined nitrogen concentrations** can be set in the component, and thus the retained austenite content, the tempering resistance or the hardening profile can be influenced.



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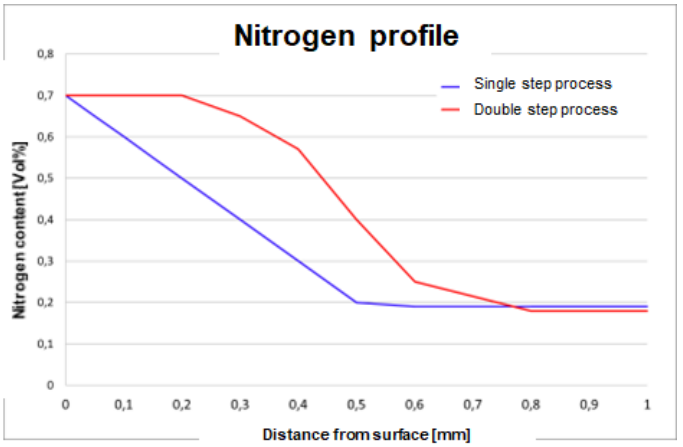
Advantages of Controlled (Gas-) Carbonitriding 3/3

Advantage 3: By controlling the N level, two-stage processes can also be run, which not only enable linear nitrogen concentration profiles in the component.



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Controlled Carbonitriding in Sealed Quench Furnaces

Since the decomposition of ammonia and thus also the amount of nitrogen, that is transferred to the component **depends both on the treatment temperature and**, in particular**, on the surface area** of the load, it can therefore happen that, despite the same heat treatment program, different heat treatment results can be achieved with different loads (e.g. full load or only a few parts).

High surface area

It would be desirable here to ensure, that the **same results can still be achieved in a repeatable manner** for batches with different batch surface areas. Another goal is the setting of **defined nitrogen contents or nitrogen profiles** in the components. For example, for a target value of 0.40 %N, a reading of about 0.38 %N (ideally, the deviations should be within ± 0.05 %N)

Low surface area

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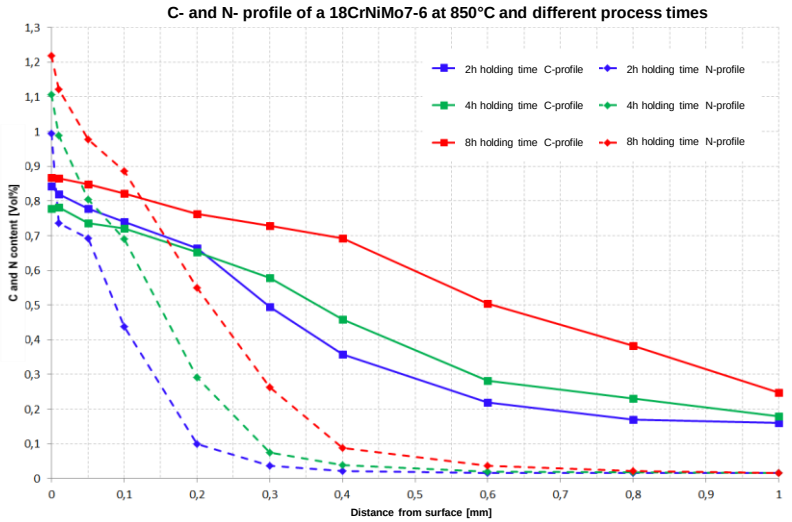
Carbonitriding results – variation of time



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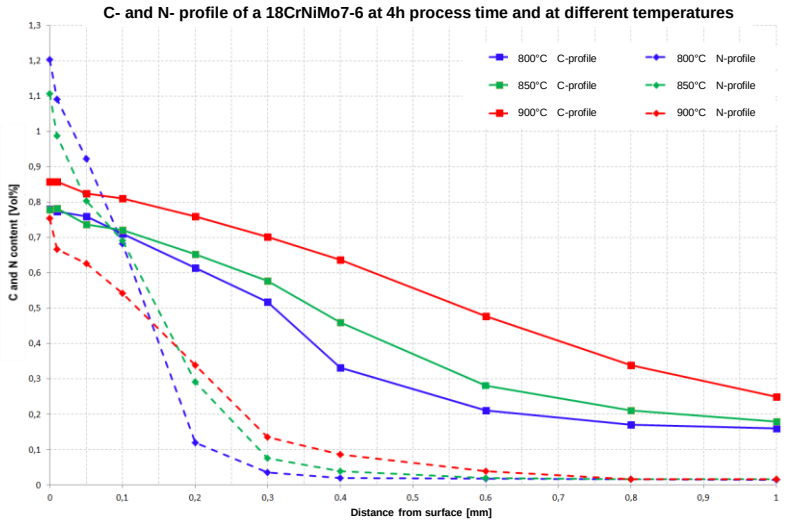
Carbonitriding results – variation of temperature



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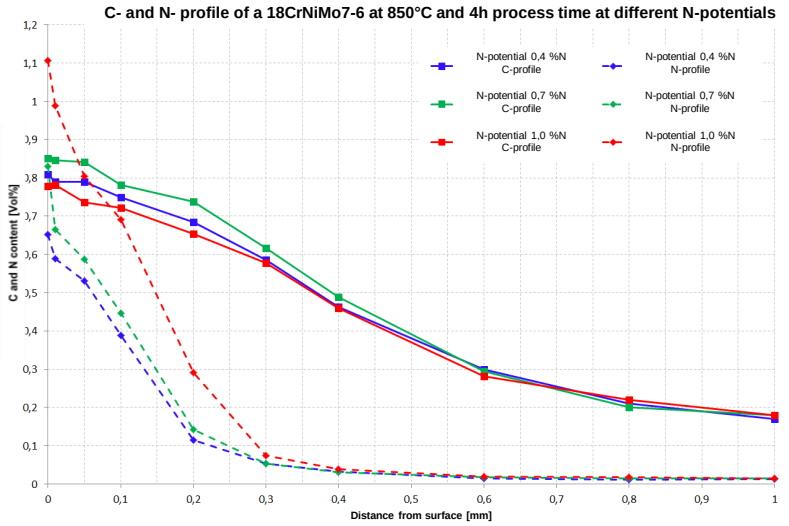
Carbonitriding results – variation of N-potential



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Conclusions and Outlook

- Furnace and Sensors for controlled carbonitriding are available
- Controlled carbonitriding gives a process advantage, especially for repeatability
- C – and N – potential must be controlled
- Process gas flow pattern is important

Controlled carbonitriding leads to controlled nitrogen profiles and better repeatability of heat treatment results, and therefore better part quality and furnace efficiency

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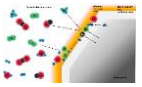
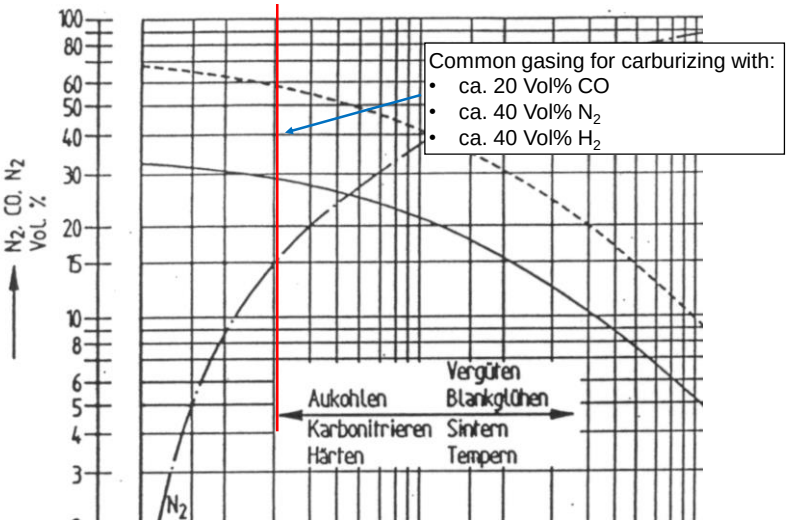
Furnace Technology for Gas Carbonitriding

Possible gas compositions with Nitrogen / Methanol





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