

Energy and Process Gas Consumption for Selected Vacuum and Atmosphere Case-Hardening Processes and Furnace Concepts – A Comparison

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Eskilstuna 07th November 2024

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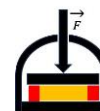
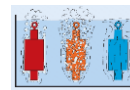
Case Hardening Today



- Carburization (or Carbonitriding) in atmosphere furnaces
- Low pressure carburization (or LPCN) in vacuum furnaces



- Quenching of batches in fluids
- Quenching of batches using high pressure gas quenching
- Hardening of single pieces in hardening presses



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Advantages of Carburization in “Atmospheres”

- In-Situ measurement and “online” calculation of the C-potential and adjusting the gas composition if applicable
- Generation of “perfect” C-profiles, by programming adopted C-potentials in each segment
- Equilibrium process
- Different gassing methods (endothermic gas, N₂-Methanol etc.)
- Various control systems (O₂, CO₂, dewpoint), also redundant
- Adjusted gas flow during the process, acc. to batch surface, process step etc.
- Gas and/or electrical heated furnaces possible
- Easily adjustable throughput (by use of large or continuous furnace)
- Lower Invest (CAPEX) - compared with vacuum technology
- Proven long system life, if regular maintained

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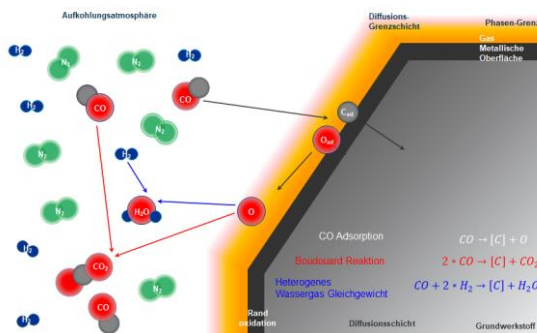
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Disadvantages of Carburization in “Atmospheres”

- Internal Oxidation (IGO)
- Carburization of “complex” geometries is difficult, e.g., small "blind holes"
- Difficult to achieve high surface carbon contents @ small CHDs
- Theoretical slightly longer process duration (compared with VAC)
- Longer conditioning duration after restart of the furnace (yearly maintenance, vacation etc.)



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Selected Controlled Variables and Sensors for „Atmosphere“ Carburization

- Temperature
- Oxygen probe
- CO/CO₂-gas analyzer
- Dewpoint sensor
- Folio test (for calibration)



Alternative and/or redundant process controls



All process variables are monitored and recorded in the **Carb-o-Prof!**

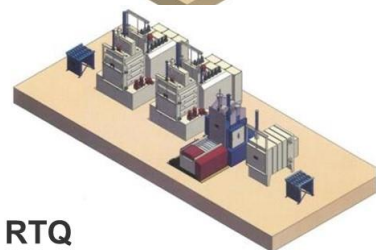
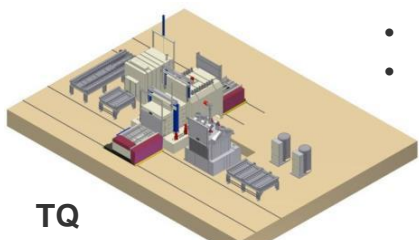
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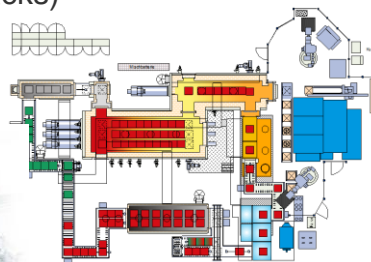


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Atmosphere Furnace Technology



- Sealed Quench Furnaces (TQ, RTQ)
- Pusher Furnaces (1 - 3 tracks)



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Advantages of Low-Pressure Carburization with Hydrocarbons

- **No internal oxidation (IGO)**
- **Carburization of complex geometries**
- High temperatures
- Higher carbon transfer
- „Faster“ carburization, shorter cycle durations
- Large CHDs
- Lower process gas consumption, lower process gas expenses
- No heat radiation, no flames (without post combustion)
- Very small CHDs
- Reduction of the H₂-content
- No furnace conditioning

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Disadvantages of Low Pressure Carburization

- **Effusion of Cr, Mn, Si, etc.**
- **Formation of soot and tar**
- **No equilibrium process**
 - **too high carbon contents of edges and tips**
 - **no compensation of partially decarburized parts during “neutral hardening”**
- Higher invest (CAPEX)
- Higher operating/ maintenance costs (OPEX)
- More complex maintenance (small leaks can stop production)
- Oil condensation in transfer and/or heating chambers (LPC with oil quench)
- (Electric heating only)

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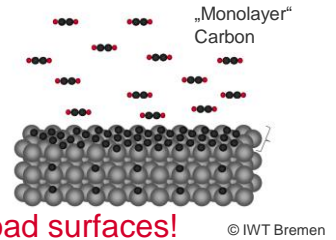
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Controlled Variables and Sensors of Low pressure Carburization

- Temperature: 850 °C – 1100 °C (1200 °C ?)
- Boost/diffusion duration: < 1 min – 10 min / > 1 min
- Gas pressure: 4 mbar – 10 mbar (abs.)
- Gas flow: ca. 200 l/m² (@950 °C)
CQI-9 requires calculation of load surfaces!
- Type of gas: Acetylene, (Propane, etc.)



Additional „Monitoring“ Sensors: - H₂-Sensor
- O₂-Sensor

➔ All process variables are monitored and recorded in the **Vacu-Prof!**

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Vacuum Furnace Technology



Multi chamber furnaces: Argos etc.



Single chamber furnaces: T²T, etc.



10 | Two chamber furnaces with oil quenching



Two chamber furnaces with high pressure gas quenching



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Energy and Process Gas Demands

Which process uses fewer resources?



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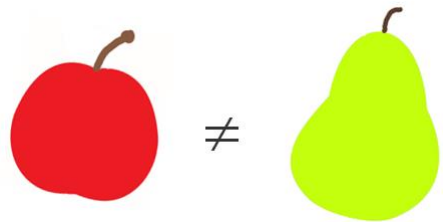
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Conditions for a Fair Comparison

- Same batch size and weight
- Same treatment temperature
- Comparable carbon profiles
- Same quenching conditions
- Plant location or location-dependent CO₂ equivalent must be known



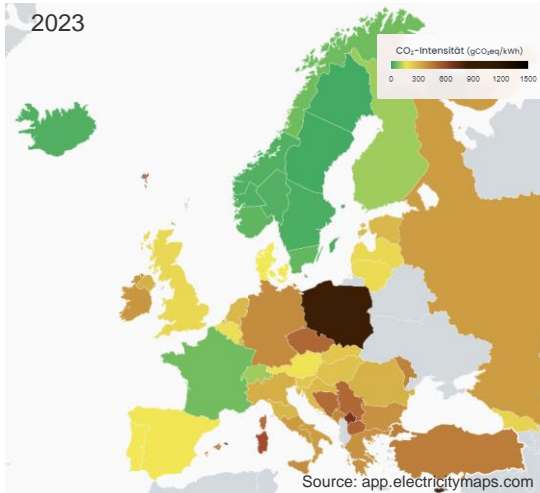
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CO₂-Equivalents Map



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CO₂-Equivalents for Selected Countries

Country	D	E	F	GB (UK)	I	PL	S	TR
Year	g CO ₂ eq/kWh							
2023	400	160	53	200	331	794	25	437
2022	474	221	91	234	402	882	26	430
2021	439	174	61	251	357	857	32	447
2020	388	181	56	234	344	828	25	426
2019	434	233	58	258	364	877	33	425

Gas heated: approx 255 gCO₂/kWh

Source: app.electricitymaps.com

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CO₂ equivalents for selected gases

Name	Alt. Name	State	kg CO ₂ eq / kg*
Acetylene	C ₂ H ₂ (Ethine)	Gaseous	2.98
Argon Ar	Ar	Gaseous	1.37
Helium He	He	Gaseous	8.56
Hydrogen H ₂	H ₂	Gaseous	12.82**
Nitrogen N ₂	N ₂	Liquid	0.22

*) Informationsblatt CO₂-Faktoren
www.bafa.de



Density (@std)	
N ₂ :	1.250 kg/m ³
C ₂ H ₂ :	1.177 kg/m ³

***) if not „green“

The production of gases generates a certain CO₂ output!



Comparison ATM / VAC(LPC): Process Duration and Process Gas Consumption

Charge 500 kg (400 kg) CHD=CD=0,95 mm C @ CD=0,35 %	ATM RTQ-M-E 		Vacuum RVFOQ 524 		Difference ATM - VAC	
	Process duration	930 °C 960 °C 1020 °C	440 min 365 min 280 min	435 min 360 min 260 min	+ 1 % + 1 % + 7 %	+ 5 min + 4 min + 18 min
Process gas	930 °C 960 °C 1020 °C	20,2 m ³ 17,5 m ³ 13,5 m ³ (CH ₄ for Endogas)	11,6 m ³ (C ₂ H ₂ : 1 m ³ + N ₂ *) 10,6 m ³) 11,0 m ³ 10,2 m ³ (C ₂ H ₂ +N ₂)	+ 75 % + 59 % + 33 %	+ 9 m ³ + 7 m ³ + 3 m ³	

*) Nitrogen (N₂) is necessary for convective heating, quenching, purging and safety. The amount can be much higher - depending on the used LPC-Process.



Comparison (E-heated) ATM / LPC

Status ~ 2010 (Germany, 380 g CO₂ eq/kWh DE2022*)

Charge 500 kg (400 kg) CHD=CD=0,95 mm C @ CD=0,35 %		ATM RTQ-M-E Insulation: Standard Brickwork	Vacuum RVFOQ 524 Insulation Standard: 40 mm	Difference ATM / VAC	
Process duration	930 °C	440 min	435 min	+ 1 %	+ 5 min
	960 °C	365 min	361 min	+ 1 %	+ 4 min
	1020 °C	277 min	259 min	+ 7 %	+ 18 min
Heating	930 °C	352 kWh	313 kWh	+ 12 %	+ 39 kWh
	960 °C	330 kWh	276 kWh	+ 20 %	+ 54 kWh
	1020 °C	317 kWh	216 kWh	+ 47 %	+101 kWh
CO2-Heating	930 °C	134 kg CO ₂	119 kg CO ₂	+ 12 %	+ 15 kg CO ₂
	960 °C	126 kg CO ₂	105 kg CO ₂	+ 20 %	+ 21 kg CO ₂
	1020 °C	120 kg CO ₂	82 kg CO ₂	+ 47 %	+ 38 kg CO ₂

*) www.nowtricity.com



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Comparison (E-heated) ATM / LPC

Status Today (Germany, 380 g CO₂ eq/kWh DE2022*)

Charge 500 kg (400 kg) CHD=CD=0,95 mm C @ CD=0,35 %		ATM RTQ-M-E Insulation: + microporous	Vacuum Insulation 40 mm + 200 mm	Difference ATM / VAC	
Process duration	930 °C	440 min	435 min	+ 1 %	+ 5 min
	960 °C	365 min	361 min	+ 1 %	+ 4 min
	1020 °C	277 min	259 min	+ 7 %	+ 18 min
Heating	930 °C	223 kWh	219 kWh	+ 2 %	+ 4 kWh
	960 °C	211 kWh	198 kWh	+ 7 %	+13 kWh
	1020 °C	204 kWh	167 kWh	+ 22 %	+ 36 kWh
CO2-Heating	930 °C	85 kg CO ₂	83 kg CO ₂	+ 2 %	+ 3 kg CO ₂
	960 °C	80 kg CO ₂	75 kg CO ₂	+ 7 %	+ 5 kg CO ₂
	1020 °C	78 kg CO ₂	64 kg CO ₂	+ 22 %	+ 14 kg CO ₂

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Effect of Load Size and Furnace Size on CO₂-Output

XL-furnace with 1.500 kg load

331.5 g CO₂ per kg load

per load	process media consumption		52,265	m ³ Erdgas
			0,000	m ³ Stickstoff
			0,000	m ³ Propan
			0,000	l Methanol
	heating gas consumption		108,32	m ³ Erdgas
			0,00	m ³ Propan
			0,00	m ³ Wasserstoff
	electrical power consumption		240,65	kWh
	of it for process		154,026	kWh
	for heating		86,63	kWh
CO ₂ Emissions		397,82	kg CO ₂	
of it for heating		243,15	kg CO ₂	
for process media		103,68	kg CO ₂	
for process e-power		50,98	kg CO ₂	

XL-furnace with 500 kg load

840.5 g CO₂ per kg load

per load	process media consumption		49,297	m ³ Erdgas
			0,000	m ³ Stickstoff
			0,000	m ³ Propan
			0,000	l Methanol
	heating gas consumption		82,81	m ³ Erdgas
			0,00	m ³ Propan
			0,00	m ³ Wasserstoff
	electrical power consumption		225,50	kWh
	of it for process		144,920	kWh
	for heating		80,58	kWh
CO ₂ Emissions		336,21	kg CO ₂	
of it for heating		190,64	kg CO ₂	
for process media		97,61	kg CO ₂	
for process e-power		47,97	kg CO ₂	

M-furnace with 500 kg load

555.5 g CO₂ per kg load

per load	process media consumption		30,406	m ³ Erdgas
			0,000	m ³ Stickstoff
			0,000	m ³ Propan
			0,000	l Methanol
	heating gas consumption		55,18	m ³ Erdgas
			0,00	m ³ Propan
			0,00	m ³ Wasserstoff
	electrical power consumption		159,28	kWh
	of it for process		112,026	kWh
	for heating		47,25	kWh
CO ₂ Emissions		222,18	kg CO ₂	
of it for heating		124,89	kg CO ₂	
for process media		60,20	kg CO ₂	
for process e-power		37,08	kg CO ₂	

Furnace: Gas heated, „endothermic gassing“; generator: E-heated
Case-hardening 930 °C, CHD 1.1 mm; steel: 16MnCr5)

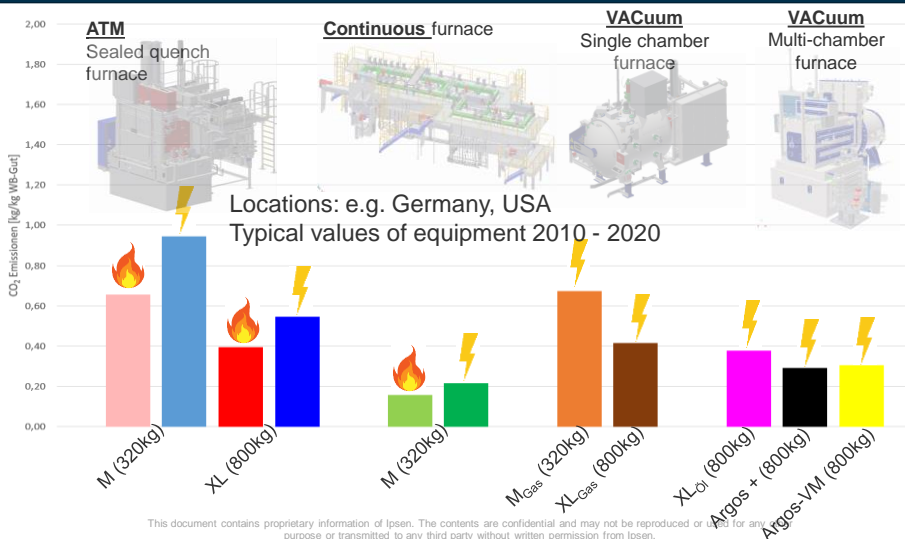
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CO₂-Emissions per kg in Different Furnace Systems, CHD 1.0 mm and a CO₂-Equivalent 350 g CO₂/kWh



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Part and Material Properties

Which process leads to better results?



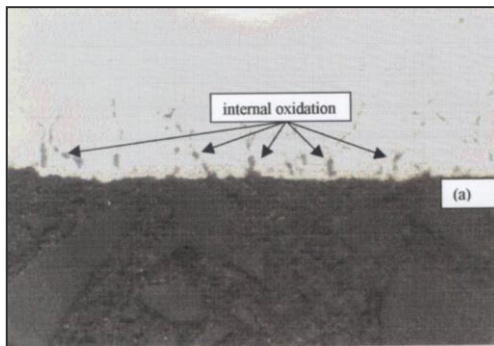
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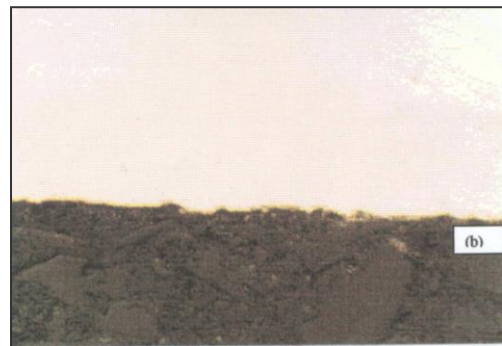


21

Condition of the Surface



Atmosphere Carburization - IGO



LPC - Effusion

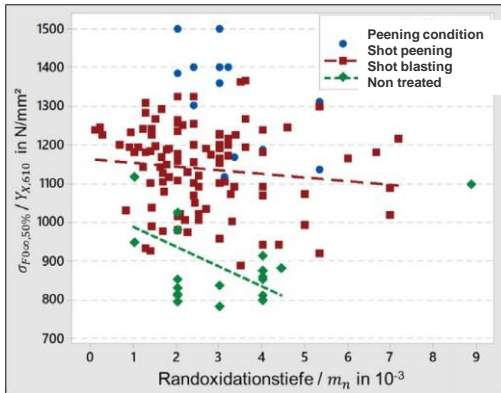
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Influence - Heat Treatment Process on the Load Capacity of Gears



The “peening condition” has a higher effect on the load capacity than the heat treatment process

“Thus, the positive effects of an IGO-free surface layer in low-pressure carburizing compared to gas carburizing (including oil quenching) according to the model, may be put into perspective.”

Bild 4-30: Einfluss des Randoxidationstiefe auf die Zahnfußtragfähigkeit (nur Referenzversuchsreihen, Anzahl: 137)
Effect of IGO depth on (tooth root) load capacity (137 reference trials)

© Abschlussbericht FVA 610 IV

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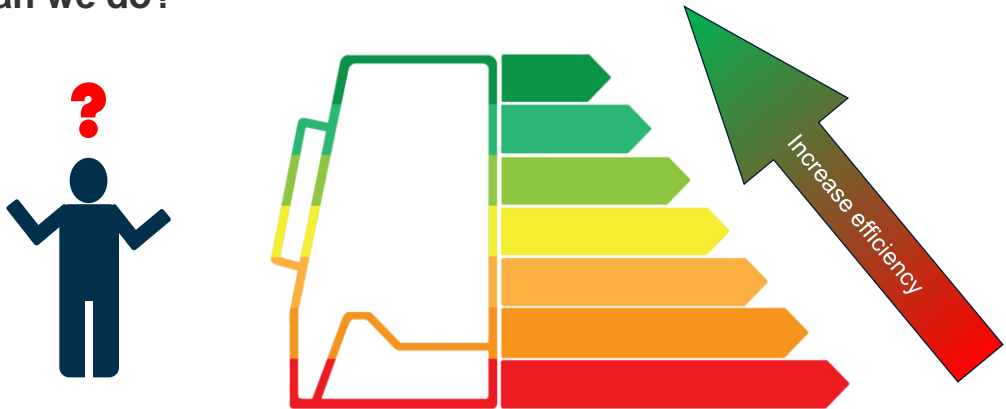
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Reducing Carbon Footprint of Furnaces

What can we do?



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Insulation, Burner Efficiency, „Green“ Hydrogen



Improved insulation

- Less heat loss

Latest burner technology

- Improved efficiency, less NOx (e. g. Recon III \Rightarrow Recon IV)

Electrical heaters

- If electrical energy (with low CO₂ equi.) is available

Use of green hydrogen (if available)

- Efficiency similar for H₂ and natural gas (approx. 80 %)

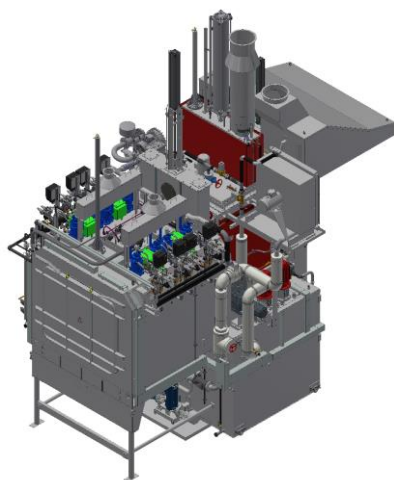
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Flexible Hybrid Heating System



● Hydrogen / multi-gas burner

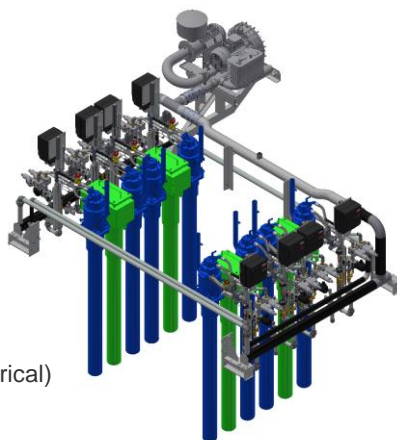
● Electric heating

8 Burners
4 Electric heaters

Also possible are:

8 Electric + 4 burners
6 Electric + 6 burners (not symmetrical)
etc.

Most of the time, one source is preferred.



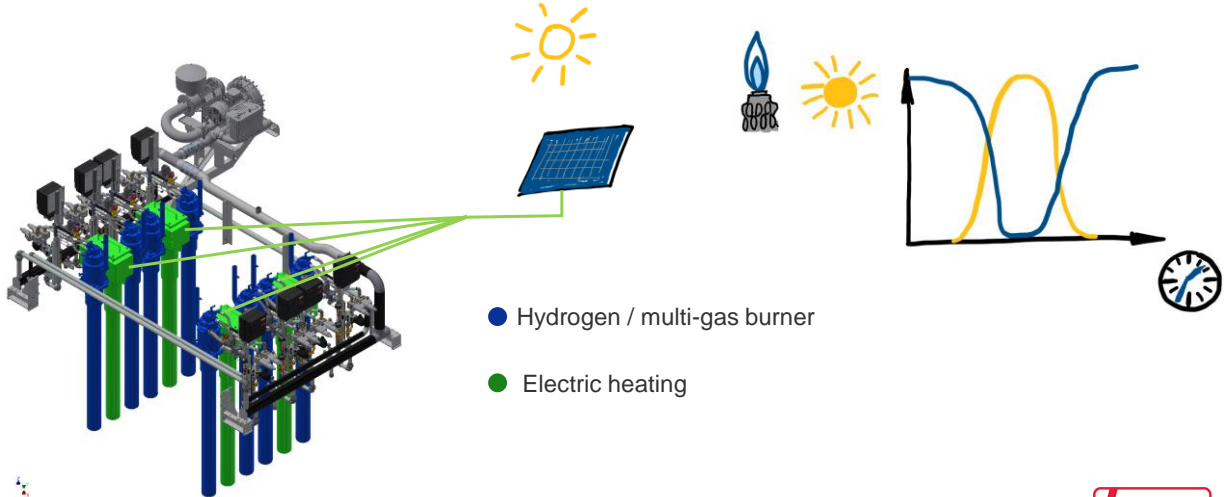
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Flexible Hybrid Heating System



- Hydrogen / multi-gas burner
- Electric heating

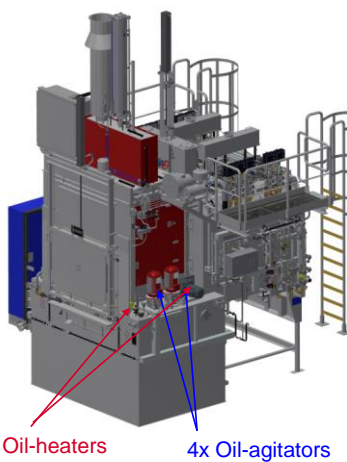
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„Intelligent“ Control of Oil Quenching System



Example 1: Optimization the use of oil-agitators

Cycle duration 10.5 h, only 30 min quenching
 4x oil agitators each 1 kW = 4 kW
 Energy demand: 10 h x 4 kW= 40 kWh

With intelligent controll only one agitator is active
 New energy demand: 10 h x 1 kW= 10 kWh (-75%)

Example 2: Optimization of oil re-cooling (after quenching)

Normal procedure: Direct re-cooling to oil set point temperature
 Maintaining the temperature by „re“-heating.

Energy saving procedure: Cooling down to a save unloading temperature, stop active cooling, natural cooling starts, approx. 30 min before quenching, compare set point with real temperature. If necessary active cooling to set point. Avoid „re“-heating.

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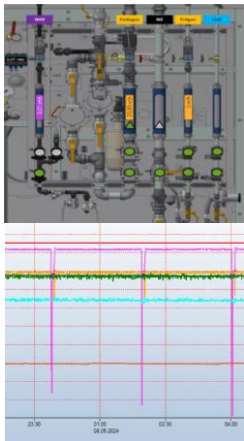


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Ipsen - GreenFlow



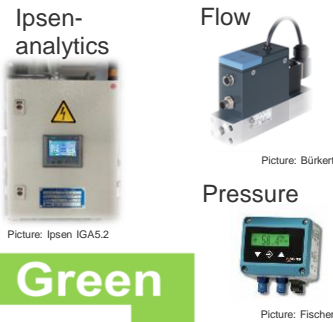
Current State of Gasing



Gasing:
~ 21 m³/h
Endogas

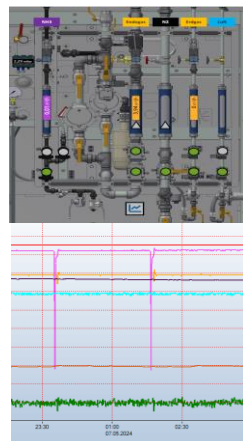
Picture: Ipsen FutureLab

Requirements



**Green
Flow**

GreenFlow Gasing



Gasing:
~ 4 m³/h*
Endogas

Picture: Ipsen FutureLab

* under GreenFlow conditions only



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Comparison ATM / VAC(LPC): Process Duration and Process Gas Consumption

Charge 500 kg (400 kg) CHD=CD=0,95 mm C @ CD=0,35 %	ATM RTQ-M-E		Vacuum RVFOQ 524		Difference ATM - VAC	
	Process duration	Process gas	Process duration	Process gas		
930 °C	440 min	20.2 m ³ → ~ 4.0 m ³	435 min	11,6 m ³ (C ₂ H ₂ : 1 m ³ + N ₂ *: 10,6 m ³)	+ 1 %	+ 5 min
960 °C	365 min	17.5 m ³ → ~ 3.5 m ³	360 min	11,0 m ³	+ 1 %	+ 4 min
1020 °C	280 min	13.5 m ³ → ~ 2.7 m ³ (CH ₄ for Endogas)	260 min	10,2 m ³ (C ₂ H ₂ +N ₂)	+ 7 %	+ 18 min

GreenFlow
up to - 80 % gas reduction

*) Nitrogen (N₂) is necessary for convective heating, quenching, purging and safety. The amount can be much higher - depending on the used LPC-Process.

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Summary and Outlook

- **There is no clear favorite**
Both methods (LPC/ATM) have advantages and disadvantages
- The shot peening of the components has a greater influence on the “fatigue strength” than the case hardening process
- Gas, oil or press hardening – depending on the requirements
- The energy demand depends on the furnace concept, **the insulation**, the carburizing temperature (and the CHD) and less on the type of carburizing
- Depending on the used energy sources and carbon donators, no “fossil” CO₂ is produced
- **Solutions to improve the efficiency of your furnaces are available!**



Thank you!

Contact: matthias.rink@ipsen.de



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