Modular heat treatment using nitriding and low-pressure carburising (Part 3)

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Vacuum heat treatment has become increasingly important in recent decades. In addition, low-pressure carburising (LPC) has been an alternative to the conventional carburising processes for more than 30 years. Its use, which was slowed down for a long time by technical and economic problems, has been further established in series production over the last 15 to 20 years. New considerations and applications now also bring together the nitriding and nitrocarburising processes with modular vacuum hardening technology. The three-part article represents the basic considerations of process and plant engineering in connection with the economic and environmental factors. Part 1 presented the plant technology (published in heat processing issue 3/2020). Part 2 explained the basics of the heat treatment processes under consideration (heat processing 4/2020). The final part at hand deals with the environmental aspects.

Vacuum heat treatment such as low-pressure carburising or brazing, but also nitriding and nitrocarburising of metallic components is determined by the parameters time, temperature, pressure, atmosphere and quenching or cooling. These process parameters can be adapted and optimised to the requirements in terms of improved component quality, energy efficiency and economic viability. Here, the industrial furnace technology has the decisive task of supporting the target values of the heat treatment process, i.e. the economic production of a component treated in a certain way from the point of view of suitability and possible applications as well as maximum service life.

In the following, the environmental aspects will be discussed, having a strong impact on the plant technology.

ENVIRONMENTAL PROTECTION & ENERGY EFFICIENCY

The Climate Protection Programme 2030 [1]

197 countries have committed themselves in the Paris Climate Convention 2015 to limiting global warming to 2 °C and to achieving extensive greenhouse gas neutrality in the second half of the century. The EU agreed to reduce CO_2 emissions by 40 % by 2030 compared to 1990 levels.

To ensure that the targets defined by the EU are met, a Europe-wide programme for major emitters was developed as early as 2005. An EU-wide emissions trading scheme has been set up for industry, energy and EU aviation (ETS) to achieve a 43 % reduction in greenhouse gas emissions by 2030 compared to 2005. The trading system regulates emissions in the member states. If a country fails to meet its targets, it must buy allowances from another country. The revenues are used for support programmes to reduce emissions.

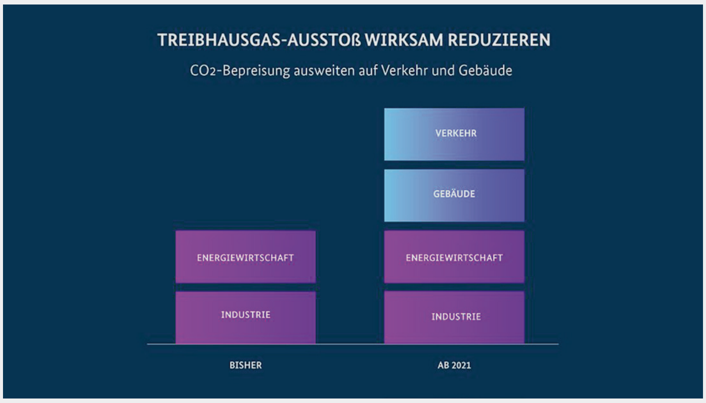

Fig. 1: CO_2 pricing

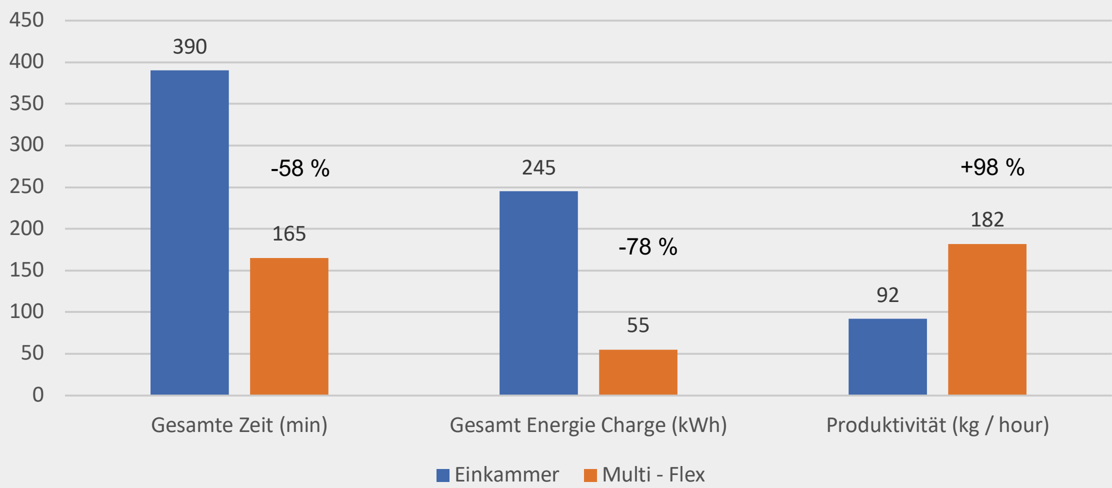

Fig. 2: Energy comparison

The missing sectors such as transport, waste, buildings, small industry and agriculture (non-ETS) are regulated in the respective states. Here, too, the EU member states have committed themselves under the EU Climate Protection Regulation to meet their defined annual targets. 11 member states have already introduced a CO_2 tax for the non-ETS sector. For this reason, a corresponding CO_2 tax has been introduced in Germany from 2021 on for these sectors (**Fig. 1**).

The CO_2 tax will be moderate at the beginning at 25 €/t but will increase annually to 55 €/t by 2026. It can be assumed that the five years will be needed to introduce new technologies and get used to the industry, and that after 2026 a massive increase in the CO_2 tax is a strategic goal of the government to further reduce emissions.

Energy comparison of ICBP® Flex vs. single chamber plant technology using the example of nitrocarburising

The comparison of the conventional retort single-chamber vacuum system technology with a modular ICBP Flex is shown below with regard to energy consumption. It should be noted that conventional nitriding plants are loaded and started manually; in the case of modular plant technologies, automation takes over this task. Time differences are not considered in **Table 1**.

Due to the fact that in single-chamber systems the furnace must always be loaded and unloaded in a cold state, the retort must be heated up with each batch, which is reflected in the time and energy consumption. Therefore, we calculate with the ICBP Flex only a one-time heating of the retort of 60 kWh instead of 60 kWh per charge, as it is necessary with a single-chamber system. The process time is identical to 120 min. The other major differences are found in the energy applied for cooling. While in the single-chamber system the retort has to be cooled each time, in the Multi-Flex system the retort remains warm and can be reloaded directly. The difference in the cooling time is even more significant. While the process in the single-chamber system takes 3 h, the cooling in the modular system is carried out in a separate cooling chamber, the batch does not block the process chamber. 5–15 min cooling time is therefore a

Table 1: Comparison of process times

	Modular Multi-Flex	Single-chamber system
	Batch 1,000 x 610 x 660	
	Gross weight = 500 kg	
Heating up to 580 °C	45 min	90 min
Energy batch	45 kWh	45 kWh
Energy retort	60 kWh für one-time heating	60 kWh
Process time	120 min	120 min
Energy for cooling the retort	0 kWh – in cooling chamber	40 kWh
Energy for cooling	10 kWh; 6 Nm³ N_2	100 kWh
Cooling time	5–15 min hidden time	3 h
Loading and unloading	5–15 min hidden time	idem

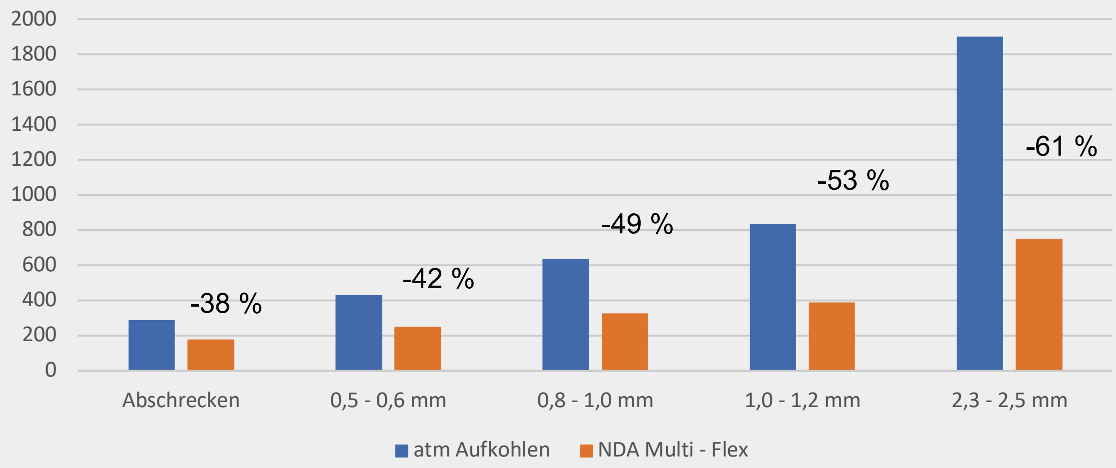

Fig. 3: Energy comparison LPC

hidden time, which means that the process chamber can be directly reloaded. This also gives the modular system concept a considerable productivity advantage. Measured in terms of the total time from loading to unloading, the ICBP Flex has twice as high (+98 %) productivity (kg/h) with 78 % less energy consumption (**Fig. 2**).

Energy comparison of ICBP Flex vs. single-chamber plant technology using the example of low-pressure carburising

If we compare the second thermochemical process, low-pressure carburising (LPC) (**Fig. 3**), comparable energy savings are achieved here. These can be derived from the same advantages as in nitriding. The quenching process is less energy-intensive in oil quenching than in gas quenching. Whereas with oil only the thermal energy absorbed in the oil has to be cooled, the high energy absorption of the turbines has to be considered with gas quenching. After gas quenching, washing is no longer necessary. This post-washing process has been considered in the energy diagram for oil quenching because it is essential. Further energy expenditure such as increased grinding work due to the oxidation layer, increased distortion (grinding allowance) and disposal of waste oil are not included in the calculation. But even without the additional parameters, a clear picture of the energy saving – Pro LPC technology – is evident. Furthermore, a clear trend can also be seen: the deeper the EHT, the more energy-saving is the LPC process in the ICBP Flex system.

Energy efficiency and funding opportunities

The German government has committed itself to reducing CO_2 emissions to 43 % of the amount emitted in 2005 in the ETS sector by 2030. In a statement by the Federal Government, CO_2 emissions in the industry sector have already fallen to 188 million t in 2016.

In order to achieve the target, support programmes have already been published that promote investments in energy-saving production. In the written version after the Climate Cabinet, the "Key points for the Climate Protection Programme 2030" states under measure 40, among others: "[...] In particular, investments in measures are promoted that are geared towards more complex and more strongly towards a systemic energy-related optimisation of production processes [...]." **Fig. 4** shows measures to promote climate-friendly technologies.

A strategy paper of the German government shows that the electrification of industrial plants is being promoted and

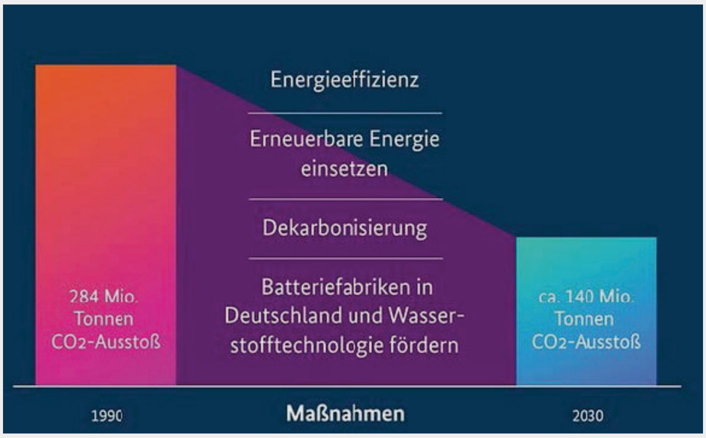

Fig. 4: Advancing climate-friendly technologies (Source: German government)

Table 2: Comparison soldering

Furnace type	Vacuum single-chamber system	ICBP Flex
Batch volume LxBxH in [mm]	1,000 x 2,000 x 1,200	1,000 x 600 x 750
Max. gross weight batch [kg]	2,000	750
Process	Nickel Löten von Wärmetauschern	
Production volume	6,000,000 WT / a	
Heat exchanger per batch	700	192
Process time batch [min]	480	265

Table 3: Total energy demand

Total energy per batch	1,683 kWh	288 kWh
Heat exchanger per batch	700	192
Total energy per heat exchanger	2.4 kWh	1.5 kWh

that energy-efficient processes are being pushed forward. For this reason, the Federal Office of Economics and Export Control (BAFA) has introduced a support programme for the introduction of energy-efficient plants. Module 4 describes the energy-related optimisation of plants and processes. Applicants can apply for subsidies for investment or additional investment costs. The subsidy is calculated on the basis of the t of CO_2 saved per year, compared to other plant technology. The maximum subsidy is a maximum of 30 % of the investment or 500 €/t of CO_2 saved per year. Small and medium-sized enterprises (SMEs) receive up to 700 €/t of CO_2 per year. It is important for the applicant that the BAFA is involved during the project phase. A certified energy consultant calculates the CO_2 savings and thus determines the funding quota.

By means of a project example, we demonstrate the energy efficiency of the modular system technology ICBP Flex compared to a single-chamber system.

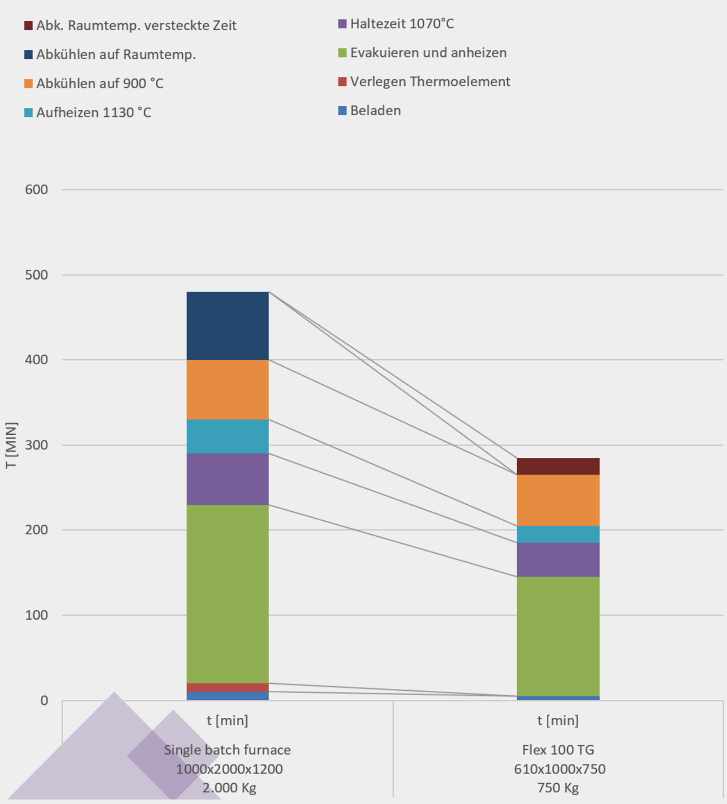

Fig. 5: Process times

Project example and energy comparisons

At first glance, the single-chamber system with its large loading volumes seems to have a clear advantage (**Table 2**). However, if the production data is analysed, it is noticeable that with larger batch volumes the heating-up times are longer and the heat loss, with longer time, drives the energy efficiency downwards.

With the summed-up process times (**Fig. 5**), three segments can be separated, which show significant time differences:

- Green: the single-chamber system must be evacuated and reheated with each batch, while the ICBP Flex is loaded under vacuum and temperature
- Orange: Heating up to 1,130 °C takes less time due to the better insulation of ICBP Flex and the smaller batch mass
- Blue: The cooling time takes place in the single chamber system and blocks it for a new process. In the ICBP Flex, cooling takes place in a separate cooling chamber (dark red) and is a hidden process time.

Let's go a step further and look at the energy distribution (**Fig. 6**) during the process, here you can see the main differences in the energy distribution:

- Orange: While the single-chamber system requires a diffusion pump, the ICBP Flex runs without

- Grey: The heat loss is much higher in the single-chamber system due to two factors: 1. determined by the extended process time and 2. design. A single-chamber system is designed for heating and cooling. To ensure that both work (halfway), the insulation thickness is not optimally designed. The heating chambers of the ICBP Flex are only designed for heating and have a corresponding insulation thickness.
- Light blue: The energy for cooling is also much higher here, in the single-chamber system. The entire system must be cooled down to room temperature, which consumes enormous amounts of energy (electricity and gas).

The energy consumption of the batch is only higher because of the higher batch dimensions. Due to the longer process time, the energy absorption of the pumping station is higher.

In **Table 3** the important parameters are summarised once again. The total energy consumption per heat exchanger during brazing in the ICBP Flex is only 1.5 kWh, i.e. 47.5 % less than in the single-chamber system technology.

Although the ICBP Flex can only load 192 heat exchangers per batch (-73 %!), productivity is only 51 % lower at 43 heat exchangers/h chamber. It is clearly shown here that increasing the batch volume has a counter-productive effect on process time and energy.

Conversely, 1.4 single-chamber vacuum systems are required for the production of 6 million heat exchangers per year. The ICBP Flex requires 2.9 soldering chambers and the energy quantity of 1,014,261 kWh is 38 % lower than in the single-chamber system. At first glance, the double number of soldering chambers may appear to be a disadvantage. **Table 4** shows the productivity: With a process time of 265 min and three soldering chambers, the modular system achieves a production flow of 88.3 min/batch compared to 240 min for the single-chamber system. This means that production interlinking runs much more frequently and regularly. Smaller batches can be set up and taken down by employees more quickly and easily and, last but not least, the space requirement of an ICBP Flex 300 is identical to two vacuum single-chamber systems. Added to this are the many automation options of a modular vacuum system, which extends to automatic leak testing and documentation of the heat exchangers.

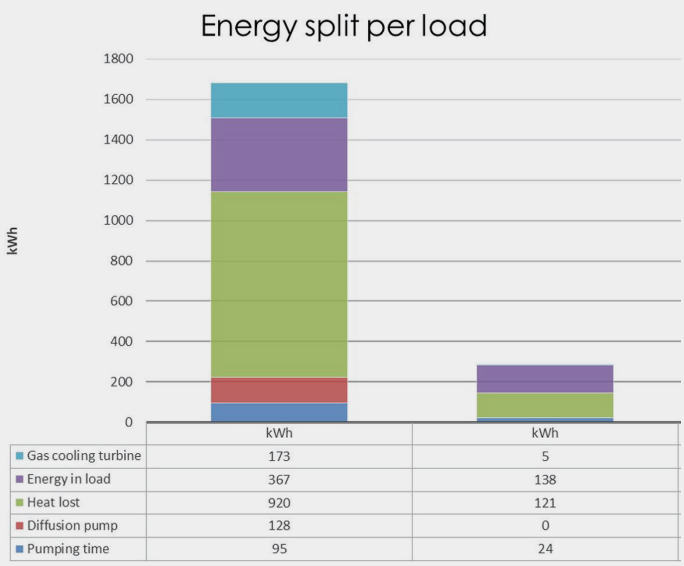

Fig. 6: Energy distribution

After the energy and production considerations, the calculation for the conveying possibilities must now also be carried out. We must point out that the BAFA calculates the individual subsidy quota on a project-related basis.

The BAFA sets a maximum subsidy of 30 % or 500 €/t of CO_2 per year in the measures to promote energy efficiency. Small and medium-sized enterprises (SMEs) receive a subsidy of 10 % or 700 €/t CO_2, whichever is cheaper for the BAFA. In addition to the one-off subsidies (**Table 5**), annual energy savings of 611,454 kWh x 0.14 €/kWh = 85,603 € are added.

SUMMARY AND OUTLOOK

Vacuum heat treatment as well as the nitriding and nitrocarburising processes have undergone a special further development and acceptance in recent years. While about

Table 4: Productivity

	Single-chamber system	ICBP Flex 300 TG
Heat exchangers per batch	700	192
Process time batch [min]	480	265
Productivity: heat exchangers/h/chamber	87.5	43
System availability @90 %, 5,400 h	472,500	234,747
Number of chambers for 6 million heat exchangers	1.4	2.9
Number batches/a	966	3,522
Total energy demand [kWh]	1,625,715	1,014,261

Table 5: Funding opportunities (*Specifications of the Federal Office of Economics and Export Control (BAFA))

	Single-chamber system	ICBP Flex 300 TG
Total energy demand [kWh]	1,625,715	1,014,261
CO_2 conversion factor*	0.537	
CO_2 [t/a]	873	545
Difference [t/a]		328
Funding 500 €/t		164,176 €
SME funding 700 €/t		229,846 €

20 years ago only special and, for example, only particularly demanding component requirements for smaller series were a reason for choosing vacuum hardening with associated low-pressure carburising, today it is possible to think in terms of large-scale production and economically interesting conditions with the aid of modular vacuum hardening systems. In addition, when selecting a suitable heat treatment process, the idea of environmental friendliness and energy efficiency is becoming more and more important, which is also best met by the vacuum hardening technology due to the low gas consumption caused by the process and the fact that it is eligible for subsidies from local authorities, states and the EU. Another good reason for choosing this technology is the requirement of integration into the production process, which is present in many places and which can be implemented in the area of lean production due to the clean operation mode.

In recent years, the aforementioned fundamental process advantages have led to a situation in which furnace and plant technology has also been able to meet the increased demands of industry, particularly with regard to component quality, part throughput and capacity, but also plant availability and ease of maintenance. New systems, in particular the modular ICBP vacuum hardening system from ECM, provide the highest standards in this area and offer a further step towards modern, environmentally friendly and therefore future-oriented heat treatment.

LITERATURE

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