Energy-efficiency in heat treatment and industrial furnace technology

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Heat treatment and/or hardening processes are subjectes to a more or less high energy consumption and accordingly produce large amounts of CO_2. It is estimated that about 40 % of the energy used in industry is consumed for all thermal processes in corresponding plants and industrial furnaces. In addition, it must be taken into account that heat treatment and/or hardening plants have a service life of more than 30 to 40 years. It is therefore obvious that the modernisation and the increase in the energy efficiency of these furnaces is a priority concern for the operators and manufacturers of these plants. The governments as well as the EU, have made corresponding funding pots available, which make investments very interesting for the operator, also from an economic point of view. This article provides information on the selection of suitable energy efficiency measures and on financial support for their implementation.

GENERALITIES

Industrial furnace manufacturers began several years ago into a significantly improve to energy efficiency of their plants in fields like furnace insulation, heating systems, waste heat utilisation and electricity consumption, as well as the integrated utilisation of waste heat for the thermal process. For example, modern furnace systems have 20 to 30 % less energy loss in the field of wall insulation compared to older systems in energy-efficiency designs. In some cases, measures by gas technology such as heat recovery can even save up to 75 % of the energy. The implementation of energy-efficient measures makes sense and is technically feasible, both by retrofitting existing systems and for corresponding new systems.

Climate neutrality is the target of the hour. What could be more obvious, that all nations should continue to act to further increase the efficiency of energy-intensive processes. For the future, the EU has set the future goals with the EU energy and climate package, i.e., the reduction of emissions and the promotion of renewable energies. With the EU's New Approach, only products that comply with this directive may then be placed on the market [1].

BASICS ON ENERGY-EFFICIENT INDUSTRIAL FURNACE

Industrial furnace industry as supplier and the heat treatment industry as operator have already started some years ago to improve the energy efficiency of their plants in the fields of furnace insulation, heating systems, waste heat utilisation and energy consumption as well as the integrated utilisation of waste heat for the thermal process. The implementation of energy-efficient measures is very feasible both by retrofitting existing plants and for corresponding new plants. The economic evaluation of a corresponding modernisation measure and the associated more efficient use of energy in heat treatment and furnace technology is always linked to the fundamental question of heat and mass transfer, i.e. how the existing heat, i.e. the energy content of a component, atmosphere or substance, can be transferred to another medium or the environment through a temperature gradient. The challenge in this balancing is that the amount of heat available can be discontinuous depending on the process and can also be dependent on the time of day or year, while the waste heat or energy must be provided according to demand. During heat treatment, components are heated to high temperatures, held and cooled again after a corresponding holding time. At temperatures up to 700 °C heat is transferred to the component mainly by (forced) convection, whereas at higher temperatures, heat radiation is increasingly responsible for heating. It is therefore understandable that, especially at lower temperatures up to about 700 °C, forced circulation is necessary for accelerated and also uniform heating of the batches. In addition to conventional circulation by

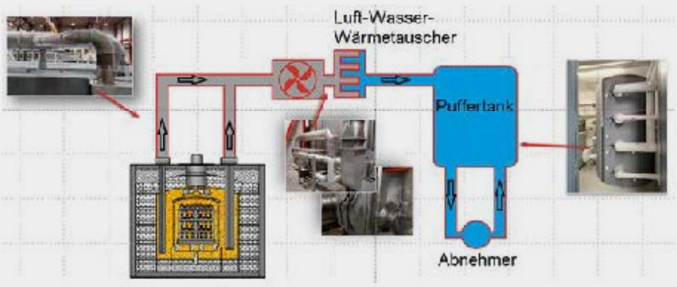

Fig. 1: Utilisation of burner waste gases in a multi-purpose chamber furnace [2].

means of hot gas fans, heating by means of high-speed convection has become established in some plant types in recent years. With the help of this technology, compact furnaces can be constructed that are characterised by very good temperature uniformity and high energy efficiency.

Optimising and increasing the circulation and flow in the industrial furnace is therefore an essential aspect of increasing energy efficiency. High-speed convection can, for example, significantly shorten continuous furnaces in terms of their heated length - in some cases by as much as 70 %. Thus, for example, the construction length of such a continuous furnace system with short temperature holding times of approx. 5 min for thick-walled sheets is only approx. 30 % of that of a pure radiation furnace or only approx. 50 % of a classic convection furnace. Overall, furnace systems can thus be designed smaller if the circulation and flow are optimised, as the thermal processes run correspondingly faster and the throughput increases as a result.

OPTIMISATION OF INSULATION

The choice or combination of thermal insulation materials and insulations has a significant influence on the characteristics of the furnace in terms of energy consumption, heating and cooling speed, energy losses, heat storage and thus energy efficiency. Fibre insulation materials, for example, have a low mechanical strength, but in contrast a high insulating and a low heat storage capacity. Heavy insulating materials such as refractories or lightweight refractory bricks have high mechanical strength, a large heat storage capacity and a lower insulating effect. The optimal combination of different insulating materials (utilisation of the insulating capacity, the storage capacity, the mechanical strength and the max. application temperature) and adaptation to the respective application is what makes energy-efficient furnace operation possible in the first place. For example, microporous thermal insulation materials can reduce the energy losses via the kiln walls by about 20 % compared to a conventional insulation structure, which usually also results in a reduction of the outer kiln wall temperature by about 10 °C.

OPTIMISATION OF BURNER TECHNOLOGY

The economy and efficiency of a heat treatment process depends on the energy consumption per component or weight. Modern industrial furnaces are usually equipped with recuperative or regenerative compact impulse flame burners, especially at high operating temperatures, which have an efficiency of about 75 % in practical use. Burners with integrated regenerators even have efficiencies of more than 85 %. Both burner types also enable furnace operation with very low CO_2 emissions while minimising NO_X emissions.

Electric heating systems are realised in a variety of different materials, depending on the application and temperature. In addition, electrically heated furnaces do not require a special permit as is the case for the installation of fuel-heated furnaces. With regard to environmental protection and occupational health and safety, the low noise and heat pollution at the place of operation should be mentioned in particular. In addition, no emissions of fuel exhaust gases occur here. In order to achieve the highest possible energy efficiency of the electric heating without exceeding the surface load, its maximum permissible element temperature must be observed.

HEAT RECOVERY

In terms of energy efficiency, waste heat must always be utilised. Today, special focus is placed on the utilisation of waste heat from burner exhaust gases (**Fig. 1**).

The heat utilisation of unused waste gases should come into focus especially when new buildings of production halls are pending and the heat utilisation could be claimed within the framework of the Energy Saving Ordinance (EnEV), since the investment usually pays off especially in the case of new buildings or complete renovation and utilisation of the heat in the heating period. The Energy Saving Ordinance (EnEV) was part of German economic administrative law. It was replaced by the Building Energy Act on 1 November 2020.

Waste heat can only be used if there is a thermodynamic gradient, i.e. a sufficiently high temperature difference between the source and the consumer. The thermal energy in cooling water during quenching processes of hardening can be used directly for a cleaning process by means of appropriate heat exchangers. The use with regard to factory heating has become established above all in new installations. It must be taken into account that large quantities of air must be moved for room heating, which in turn make the provision of conveying energy necessary. Heating via underfloor is simpler and more energy-efficient and also offers interesting perspectives for outdoor areas (car parks, driveways). The use of hot water for sanitary facilities is also a very interesting option in terms of waste heat utilisation, especially from an economic point of view. In this case, shower and heating water with a relatively high temperature is delivered to a hot water tank for the above-mentioned demand via an additional water-water heat exchanger. For larger quantities of heat, it also makes sense to feed it into public district heating networks. From an energy point of view, all measures operated via cooling water/heat exchangers can basically be improved by increasing the permissible cooling water temperature at the consumers.

The recooling of oil quenching baths is usually carried out via oil-water or oil-air plate heat exchangers, which are to be integrated into the circuits according to the cooling of water. The heating of cleaning systems (40-80 °C) or component drying after cleaning can be carried out by using waste heat from oil quenching baths in the same way via heat exchangers. There should be temperature differences between the oil and cleaning baths of more than 20 °C, which is usually not a problem if suitable systems are selected. If waste heat from oil baths is used for drying (with or without a vapour condenser) on continuous systems that require about 20,000 m^3 of cooling water per year, energy savings of about 15 to 20 kW are possible, so that amortisation times for these measures of three years can be expected for these systems.

"So there are enough possibilities, you just have to identify them and implement them technically", if necessary with the support of suitable consultancies, such as IBW Dr. Irretier". The authors of the article have been dealing with these topics for years and advise, train and provide appropriate solutions for the energy-efficient design of heat treatment processes and industrial furnaces.

ENERGY EFFICIENCY, HEAT RECOVERY AND FUNDING OPPORTUNITIES

Since the Paris Climate Agreement, "the world" has committed itself to achieving far-reaching greenhouse gas neutrality. The EU and Germany have committed themselves to hit their defined annual targets within the framework of the EU Climate Protection Regulation. Many member states have already introduced a CO_2 tax. The CO_2 tax in Germany was "still" moderate at €25/t when it is introduced in 2021, but it will rise annually to €55/t by 2026. It can be assumed that the five years for the introduction of new technologies and for the industry to get used to the tax are to be regarded as a long time, and that after 2026 a massive increase in the CO_2 tax is a strategic goal of the government in order to further reduce emissions [3].

In order to achieve the climate targets in the EU and especially in Germany, subsidy programmes have been introduced to promote investments in energy-saving production. The written version states, among other things, investments are promoted in measures that are geared towards more complex and more systemic energy-related optimisation of production processes. For this reason, the Federal Office of Economics and Export Control (BAFA) has introduced a funding programme for the introduction of energy-efficient systems. As an applicant, one can apply for subsidies for investment or also additional investment costs.

First of all, these considerations raise to the question, who is eligible to apply in the first place. These are domestic and foreign companies in the commercial sector (manufacturing, crafts, trade and other service industries), the majority of which are privately owned, in each case with a permanent establishment or branch in Germany [5].

The funding contents are primarily:

Module 1: Measures to increase energy efficiency (replacement and new acquisition)

Module 2: Measures to provide process heat from renewable energies

Module 3: Measurement and control technology, energy management software

Module 4: Measures to increase energy or resource efficiency

The definition of the funding content is linked to corresponding funding rates or repayment subsidies.

Module 1:
Subsidy of up to 30% of the eligible costs (for small and medium-sized enterprises there is a bonus of 10 percentage points; maximum subsidy 200,000 € per project)

Module 2:
Process heat generation from renewable energies
Subsidy of up to 45% of the eligible costs (for small and medium-sized enterprises there is a bonus of 10 percentage points; subsidy according to de-minimis and AGVO (Article 41) possible)

Module 3:
Subsidy of up to 30% of the eligible costs (for small and medium-sized enterprises there is a bonus of 10 percentage points, funding according to de-minimis and AGVO (Articles 36, 38) possible)

Module 4:
Subsidy of up to 30% of the eligible costs, but no more than € 500 per tonne of CO_2eq saved per year (SMEs: up to 40% of the eligible costs, but no more than € 900 per tonne of CO_2eq saved per year; funding under de minimis and GBER (Articles 36 + 38 + 41 + 46) possible).

In contrast, the following measures are not eligible for funding and are excluded:

Table 1: Funding programmes

Funding programme	Funding type	Usage
KfW Funding programme 295	Loan with 30% repayment subsidy	Waste heat utilization
QST-Module 4 of BAFA	30 % investment cost subsidy	Waste heat utilization
Cross-cutting technologies	30 % investment cost subsidy (max. 30 T€)	Energy efficient components
climate protection	30 % investment cost subsidy (max. 200 T€)	Energy efficient lighting

- Measures that an official order obliges to be carried out.
- Measures that have already been started
- Measures affecting the fabric of buildings
- Measures affecting primary agricultural production
- Used plants and new plants with used plant components
- Research and development projects
- Own work
- Services between partner enterprises and affiliated enterprises
- Personnel and operating costs, production costs, taxes
- Vehicles for off-site transport,
- Energy and resource savings, through reduction of production
- CO_2 savings, by replacing energy sources with fossil fuels
- CO_2 savings, by operating plants with fossil energy sources
- Acquisition of plants operated with coal or oil
- Measures on plants that are operated with coal
- Switching from a renewable energy source to a fossil energy source

The grant or repayment subsidy is calculated on the basis of the eligible additional investment and eligible investment costs in the case of support under the de minimis rule. In addition, the costs for the preparation of a savings concept and implementation support for the subsidised measure by external energy consultants are eligible for funding.

The payback period of the entire project, in terms of the energy or resources saved, must be more than 3 years in total without claiming a subsidy. Incidental costs are also eligible [5]. The following table shows the most important funding programmes:

"At first glance, the project funding described seems complex - at second glance, with the appropriate technical and advisory expertise, it is reasonable in terms of the effort involved". Ultimately, the subsidy is calculated on the basis of the tonne of CO_2 saved per year, compared to another system technology, with the maximum subsidy amount being the investment (or €500 per tonne of CO_2 saved) per year. Small and medium-sized enterprises (SMEs) receive up to €700 per tonne of CO_2 saved per year. It is important for the applicant that BAFA is involved during the project phase. A certified energy consultant calculates the CO_2 savings and thus determines the funding rate [3].

ENERGY EFFICIENCY GUIDE

In order to be able to correctly assess the situation with regard to energy efficiency in the company as a basis for a funding application, all available operational energy data should first be determined. The inventory is made up of both the available performance and consumption data of all furnace systems and the data of peripheral systems in the hardening shop (gas, electricity and water consumption). The energy inventory also includes an assessment of the energy efficiency of the thermal insulation of the furnaces, the condition of the furnace doors and seals, and the heating systems.

After determining the various energy data, the possible weak points are examined. These depend on the type of location and the existing furnace systems. Weak points can occur where energy is used or can escape in an uncontrolled manner, for example at thermal bridges in the stoves.

Based on this inventory and the numerical values determined in the as-is analysis, feasible energy efficiency measures are proposed:

1. problem description, objective, delimitation
2. overview of heat treatment processes
3. review of the site plans of the plant
4. listing of the heat treated quantities and batches
5. compilation of the technical data of the furnace installations
6. review of maintenance and installation plans for all media
7. listing of the main consumers according to energy type
8. compilation of consumption and power measurements
9. listing of energy sources with invoices and quantities
10. review of technical documentation on waste disposal systems

Subsequently, a plan of action is drawn up and conclusions from the investigations carried out for the improvement of the operational energy situation are presented. Costs and their budgeting for the planned optimisations are worked out and discussed. 5.

CONCLUSION AND RECOMMENDATIONS

Energy efficiency and heat recovery in industrial plants and especially in energy-intensive plants in the hardening industry is currently "on everyone's lips". This paper shows possibilities to implement energy efficiency and heat recovery in heat treatment and hardening plants and gives an introduction to the possibilities to increase energy efficiency in hardening plants. In addition, the article is to be understood as a guideline to identify funding opportunities for energy efficiency with regard to increasing economic efficiency and to implement the corresponding possibilities.

Energy efficiency and heat recovery have received increasing attention in all areas of production in recent years. The general approach of resource conservation and environmental protection and the striving for cost reduction associated with rising energy prices are currently triggering a series of measures. In the future, we can expect a further increase in the demand for energy-efficient plants and processes, especially due to the further tightening of national and international legal regulations. This may require the professional support of an external consulting firm such as IBW Dr. Irretier.

Energy-efficient action is now a "MUST" in industrial processes, both from an environmental and a commercial point of view. Industrial furnace construction, in cooperation with heat treatment and hardening shops, will continue to use all possibilities for exploiting the efficiency increases that result on the one hand from the optimisation of individual processes, and on the other hand, and this with the far greater potential, from the "holistic" consideration and improvement of interlinked process and production sequences - under the condition of economic benefit !

It is necessary to record and balance cross-process material and energy flows in the companies and to use the technical and economic possibilities of energy saving - as presented in this technical report - e.g. by shortening process times, energy storage, waste heat utilisation or energy recovery. Implement strategies taking into account what is technically feasible and compliance with regulations and environmentally relevant requirements. Holistic approaches to thermal processes, taking into account all influencing variables, are essential and ultimately enable technically feasible and commercially interesting solutions on the topic of "energy efficiency". Here it is necessary to determine the potentials from heat treatment, furnace construction, heating and cooling technology.

The procedure or "red thread" is "obvious". After taking stock of the situation, the employees from planning, hardening shop and maintenance should discuss the possibilities of financial support, ideally under the moderation of a technical expert. Once the funding concept has been drawn up with proof of the energy saving potential and ideally approved by the funding institutions, the measure is commissioned from the supplier. After completion of the measure, savings results are determined and confirmed, so that the expected subsidy amount or repayment grant is finally claimed.

LITERATURE

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