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Control of C potential in gas carburizing plants – A new approach to a holistic view?!

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Control of C potential in gas carburizing plants – A new approach to a holistic view?!

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The highly specialized processes used in gas carburization plants require suitably adapted automation technology. Hereby, the operator expects simple, clear, and unmistakable handling during the generation and implementation of recipes. The new program controller shown in Fig. 1 meets these demands. Thanks to a consistent programming method oriented along the processing sequence, the balancing act between user-friendliness and handling complex thermo-chemical processes has been achieved. This article describes the process requirements and the corresponding solutions.

Two widespread principles are applied in the field of gas carburizing furnaces. They are found in numerous versions of the continuous furnace and the batch furnace.

The batch furnace is a closed compartment, in which a batch of material is exposed to different temperatures and gas concentrations for certain periods. In a continuous furnace, on the other hand, the batch is transported through different temperature and gas concentration zones. In terms of process control, a continuous furnace is seen simply as a series of batch furnaces, as every zone is maintained at defined, constant values. For this, the zones must be provided with variable setpoints to suit the process duration and profile. Therefore, we will only be considering the batch furnace.

The purpose of such a furnace usually involves the treatment of a steel component in the austenitic condition – the batch – by enriching its surface region with carbon to obtain the required surface hardness. Hereby, a certain temperature profile must be maintained. In addition, the batch must be enveloped in a gas atmosphere to permit the defined and controlled delivery of carbon.

In most cases, a "carrier gas" is used, which is either enriched with alkenes as the carbon carrier (e.g. natural gas or propane) or diluted with air. At higher temperatures (above 800 °C), such a gas mixture develops a carbon activity that can be viewed as the "driving force" with which the carbon penetrates into the metal.

So far, there is no direct method for measuring the carbon activity or the resulting flow of carbons into the material. Therefore, these values are determined by means of indirect measurements. One widely used method for determining the C potential is by using oxygen sensors. This involves measuring an oxygen partial pressure (**Fig. 1**), from which the corresponding C potential is calculated, whereby the additional parameter represented by the protective gas is assumed to be known and in chemical equilibrium.

The C potential "Cp" is a measurand that has resulted from practice. Cp is defined as the percentage weight increase of a pure iron sample (test film) before and after carbon enrichment, and is specified in "weight %". Although the weight increase can be demonstrated easily with the help of scales, this method has been replaced by newer measurement procedures. However, they do not illustrate the carburizing process as clearly.

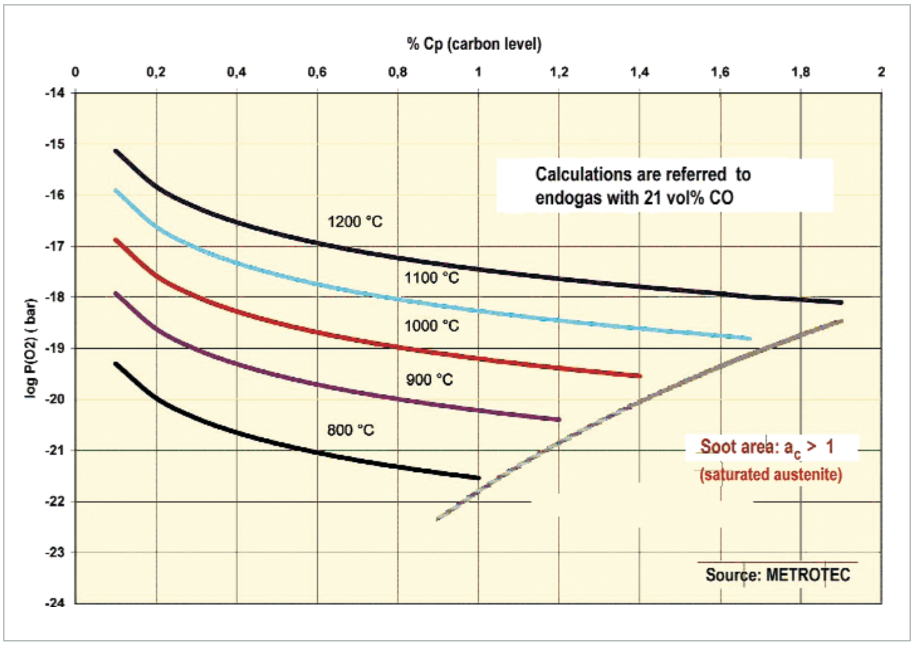

Fig. 1: C potential as a function of oxygen partial pressure at various temperatures

Table 1: Creation of a recipe

Recipe	Setpoint	Batch result
Without alloying factor	Desired C potential in the atmosphere	Higher or lower than setpoint, depending on alloy
With alloying factor	Desired C potential in the batch	= desired value

Introduction to the alloying factors

It seems obvious to use the C potential as the control factor during gas carburization. In real life, however, the components are not made of pure iron, but consist of various metal alloys. As a result, they exhibit a different C potential after treatment than the value determined by means of weighing (film sample). The reason for this lies in the material composition. Some alloying elements support carbon solubility, whilst others prevent it.

Therefore, an "alloying factor" was introduced, which is intended to account for these facts. It is calculated from:

$$C_{pL} = 10^{(\log Cp - 0{,}05\%Si - 0{,}013\%Mn + 0{,}014\%Ni - 0{,}013\%Mo)}$$

whereby C_{pL} represents the C potential in the alloyed system.

Program controller for confident operation

For the first time, this new program controller for C potential gives operators the possibility of creating recipes that take the alloying factor directly into account. Consequently, the creation of a recipe according to **Table 1** means the following:

One consequence of increasing controller miniaturization is that fewer operating buttons are available to handle an increasing number of functions. This is mostly solved by means of multi-function keys. For the plant operator in a critical situation, this can lead to the problem of having to make the right choice very quickly from several options.

The new concept has solved this problem by providing decentralized operating elements (pushbuttons, key switches), whose functions are unambiguous and clear: e.g. Start, Stop, Reset, Jump (to a predefined position in the program), Batch in the furnace, Furnace empty, etc.

Detailed and frequently overloaded graphics of controllers and control functions – which are usually of interest to the operator only when they no longer work – have been transferred to the commissioning and service level. This is also where all automatic functions such as sensor flushing, gas parameters, process factors, pre-conditioning, etc. are located. For the operator at the furnace, only recipes, process values, setpoints, and alarms are accessible.

Control concept

Here, we will only describe how the atmosphere in the reaction chamber (the retort) is controlled during a batch process (**Fig. 2**). All other plant control functions such as material charging and removal, subsequent quenching (e.g. oil bath), flaring of combustible waste gas, or monitoring of safety conditions (e.g. risk of explosion, exceeded temperature, etc.) will not be viewed in detail.

Here, the aim of process technology is to create and maintain a furnace atmosphere with specific, constant properties (C potential, temperature) within tight tolerances, in order to obtain reliable evidence about the quality of the carburizing process.

However, before actual carburizing can begin, the process must pass through various preparatory stages. The respective setpoints for temperature and C potential are supplied by a programmer with bandwidth monitoring. In general, the carrier gas flow is fixed. Depending on process requirements, the atmosphere must either be enriched and/or diluted. Therefore, the atmosphere controllers shown exhibit either 2-point or 3-point behaviour.

The actual C potential (= 0 ... ≈2, value without units) is calculated as a function of the EMF (O_2 sensor) and the process temperature as well as several material constants. The most important process phases are described below:

- Charging: Introduction of the cold material into the heated reaction chamber (temperature drop).
- Heating and dwell: Program start; Heating up and lineout at the setpoint temperature (e.g. 930 °C) with subsequent short dwell time (pause until core and surface temperature are equal).
- Carburizing: Release of carrier and carburizing gas (approx. 850 °C), and lineout to programmed Cp setpoint (e.g. 1,3). The carburizing duration lies in a range from minutes up to days, and depends on the required carbon penetration depth (according to the intended use of the batch material).
- Diffusion: Equalization of the carbon concentration in the material's surface region (reduction to approx. Cp = 0,8).
- Removal and cooling: Controller switch-off. Fast cooling; freezing of crystalline structures to obtain the

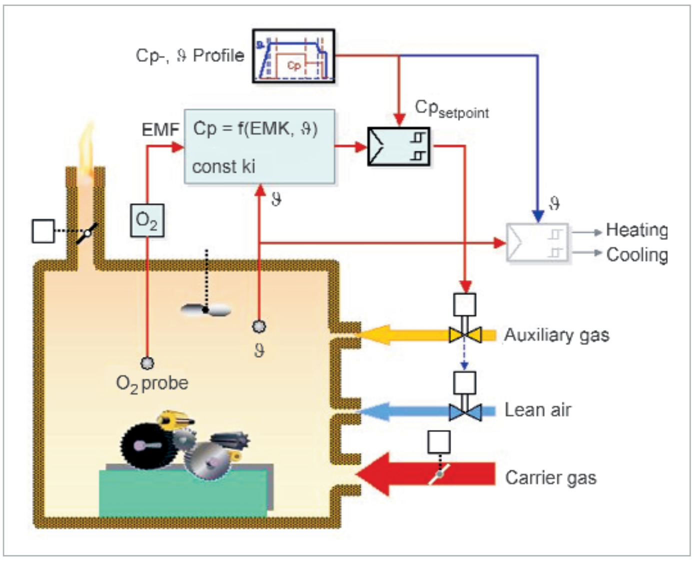

Fig. 2: Example for control of the carburizing process in a batch furnace

Fig. 3: Process overview

Fig. 4: Operation of Cp controller

Fig. 5: Direct access to program controller

required degree of hardness (e.g. according to Vickers VH).

- Batch pre-conditioning: Recipe selection, sensor flushing and testing

For the purpose of disturbance prevention, the actual values of temperature and C potential are monitored continuously within a defined bandwidth. Soot alarm is triggered, if the Cp value exceeds the setpoint for an excessively long time. This is done by additional limit monitoring of the time integral $\Delta Cp * t$.

Prior to every batch, the sensor is flushed (cleaned) with air and then checked whether the previously stored measurement value is reached again within a specified time. If this is not the case, a sensor alarm is triggered.

Several optional functions can be selected:

- Control (3-point) of indirect heating and cooling
- Sequencing or control of the pressure in the reaction chamber during the carburizing phase
- Adjusting and monitoring the carrier gas flow
- Intermediate cooling (application-dependent; phase transformation, crystalline structural change).

The measurement inputs for O_2 sensor and temperature can be calibrated in the Service mode.

Safe operation and display

The user-friendliness mentioned at the outset is achieved by means of consistent menu guidance in the user's language. Via the master menu (displayed automatically after power-up), other operating and display pages are selectable, for example a process survey, controller, programmer, trend, batch parameters, and service. **Fig. 3** gives an overview of the most important process conditions. The Cp controller and programmer are shown in **Fig. 4 and 5** respectively.

Event-driven color changes, direct/inverse display, as well as the possibility of a flashing display inform the operator immediately about the process conditions – also at a distance – and whether "everything is within limits" or if there is a disturbance.

Waiting for START: → green background

Program is running → green display

Caution: Sensitive area → red display

Acute disturbance → red background

Should a critical process condition arise, an alarm page can be called automatically, in which up to 48 alarms (with/without acknowledgement) are listed in the sequence of their occurrence.

Extensions

It is not a contradiction of the above arguments in favor of a simple atmosphere controller, to use a PC as a superordinate process guidance level. For example, the PC can handle the batch reports with the MSI-C software tool as "process monitor" or it can be used to prepare recipes.

Apart from the online calculation of diffusion equations to determine and display (x/y axes) the carbon distribution in the material, the batch data with all the process parameters are stored in a database. Simple search criteria such as date, job no., etc. permit these data to be retrieved, e.g. to create a report with graphical representations of the process curves.

Additional extensions for the continuous calculation and presetting of process setpoints from a specified hardness profile are being tested.

Conclusion

The complex C potential calculation, the signal interconnections, and all the described control and monitoring functions are implemented with a compact multi-function unit, which features a high-impedance O_2 sensor input in addition to standard signals and a temperature input. All important process values are displayed and operated on the unit's front.

Operator guidance is reduced to the essentials. All other settings, adjustments, and displays have been moved to subordinate menu levels, access to which can even be password-protected. A clear display with color options for visual signaling purposes reduces the risk of operating errors, and ensures fast and confident operator actions in case of a disturbance.

In short, a top-level economical solution is now available, fitted with a serial interface for easy linking into a supervisory system.

Literature

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