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Technology Update

Accelerated and improved carburising with MFC controlled nitrogen-methanol atmospheres

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The ability to produce high quality and consistent carburised parts requires precise control of the carburising atmosphere. The use of mass flow controllers (MFCs) is described as a means to regulate the furnace atmosphere composition as well as to improve quality of the heat treated parts by the use of a consistent atmosphere. Furthermore, the increasing productivity by the use of accelerated carburising (ACP) and MFCs is reported.

Carbon steel components have been routinely carburised and hardened by commercial heat treater and part producers using both endothermic and nitrogen methanol atmospheres for a number of years. It has become more difficult to produce parts with competitive pricing, because of the increase in quality standards and higher pressure on costs. Atmosphere control systems for carburising processes are well known in the industry and are typically standard equipment. However, variations in the carburising quality, and therefore hardness, are normal day-to-day problems when using these control systems. The main reason for these variations is that the controller is calculating the carbon potential based on a fixed value for the CO level, which is manually set in the controller. Both endothermic atmospheres and manual regulated nitrogen-methanol atmospheres show variations in the composition based on:

- insufficient flow regulation of natural gas and air as well as changes in the natural gas composition
- pressure variations or wrong flow settings in the nitrogen or methanol line.[1]

Using a nitrogen-methanol atmosphere, controlled by mass flow controllers (MFCs), can solve these problems and improve the carburising quality. MFCs can regulate the flow rates independent of pressure and temperature, they can compensate all variations in the line pressure, and they will keep the blend, and therefore the CO level in the furnace constant. Using this MFC technology also provides the opportunity to implement the accelerated carburising process (ACP), which can shorten the carburising cycle by up to 20% and significantly increase productivity.[2] Trials showing the feasibility and benefits of accelerating carburising were carried out at an Air Products customer's site (Mubea, Germany), in a chamber furnace.

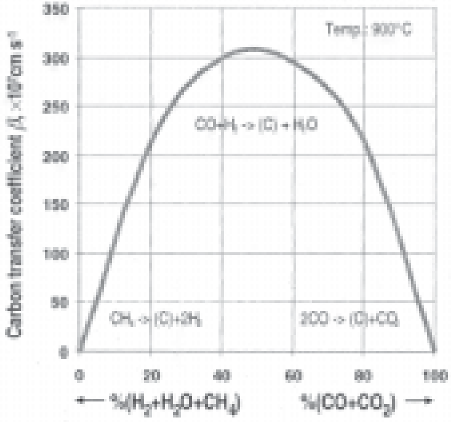
Carburising process

Since the theory of the carburising process as well as the carburising reactions are well known, this section only summarises the basics for explaining the benefits of a MFC control panel. The carburising process itself can be divided into two phases, which are described below.

The first phase is the carbon deposition phase, in which the carbon containing species from the atmosphere are transferred to the steel surface. The deposition of carbon on the steel surface then occurs by thermal decomposition of the carbon containing species and the created carbon diffuses into the steel surface. The main component containing carbon in carburising atmospheres is carbon monoxide (CO), which produces carbon by the known carburising reactions.[3] This process can be influenced by process temperature and atmosphere composition. The amount of carbon diffusing into the steel surface is related to the carbon transfer coefficient *ß* and the gradient of the carbon level between the atmosphere C_p and the steel surface C_s. The amount of carbon *m*, diffusing into the steel can be described using the equation

$$m = ß(C_p - C_s) \quad \text{(1)}$$

Figure 1 shows the dependency of the carbon transfer coefficient on the carburising atmosphere composition at 900 °C.[3,4] The maximum carburising speed in the deposition phase can be reached with an atmosphere composition containing 50%CO and 50%H_2.



1 *Carbon transfer coefficient based on CO and H_2 levels at 900 °C: after Ref. 3*

In the second phase, the carbon diffusion phase, surface carbon diffuses from the steel surface into the core. This process is expressed by the laws of diffusion (Second Law of Fick) and depends on the diffusion coefficient *D*. The change in carbon concentration *C* in the part is described by the equation

$$dC/dt = D\, d^2C/dx^2 \quad \text{(2)}$$

where *D* is the diffusion coefficient, dependant on the temperature, *t* is the time and *x* is depth beneath the surface.[5,6] This phase can only be influenced by the carburising time, the process temperature, and the difference in the carbon content between the steel surface and the core (the carbon gradient). It is not influenced by the composition of the atmosphere.

Carbon control systems

Oxygen probes are often used for monitoring the carbon potential in carburising atmospheres. To calculate the carbon potential from the signal of the oxygen probe, it is necessary to know the temperature and the CO level

$$E = 2.303RT/(4F) \log(pO_2/p'O_2) \quad \text{(3)}$$

$$E = 0.0992T[(\log pCO - 1.995 - 0\ 15C_p) - \log C_p] - 816.1 \quad \text{(4)}$$

where E is the electromotive force of the oxygen probe, F is the Faraday constant, pO_2 is the oxygen partial pressure of the furnace atmosphere, $p'O_2$ is the oxygen partial pressure of air, T is the carburising temperature, and pCO is the CO partial pressure of the carburising atmosphere.[3,7]

In normal carbon potential control systems, pO_2 and T are measured by the oxygen probe but the CO level is set manually in the controller, i.e. 20%CO and 40%H_2. For the accurate regulation of the carburising atmosphere, natural gas (or other hydrocarbons) is added to increase the carbon potential (or air can be added to decrease carbon potential). If the CO level in the furnace varies from the input value for the controller, then the calculated and regulated C potential will be incorrect for the existing atmosphere. This results in varying carburising profiles. It is therefore very important to control the introduced carburising atmosphere to match the input value to the controller.

Carburising atmospheres based on nitrogen-methanol systems

Carburising atmospheres based on endothermic generators are produced by partial burning of natural gas and air, and produce mainly a composition of 20%CO, 40%H_2, residual CO_2 and moisture balanced with nitrogen. Several major problems such as maintenance costs, availability, and reliability of atmosphere composition convinced a large number of heat treatment shops to replace the generators and use the direct injection method of nitrogen and methanol to produce the carburising atmosphere.

By cracking methanol directly in the furnace the composition of carburising atmospheres can be adjusted

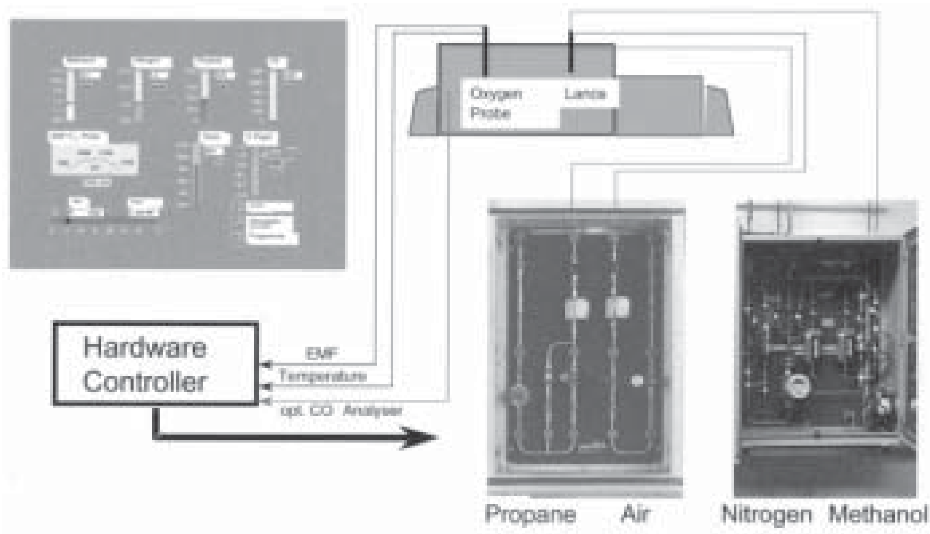
$$CH_3OH + xN_2 \rightarrow CO + 2H_2 + xN_2 \quad (5)$$

Traditionally, although a blend of nitrogen and methanol is used to create 20%CO and 40%H_2, the CO level can be increased up to 33%.

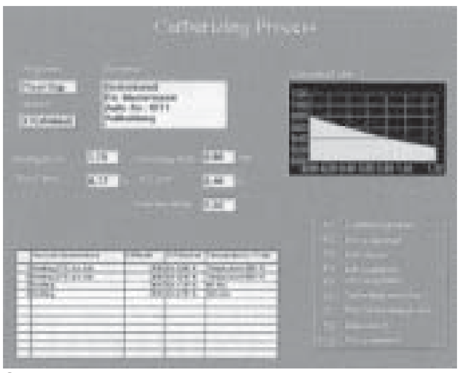
MFC controlled carburising process

The MFC technology as well as the accelerated carburising process can be installed as a complete atmosphere control system including control of the carbon potential. MFC technology can also be implemented in existing systems, if control of the carbon potential already exists. For a simple explanation, a complete system (Fig. 2) is described here.[1]

The control unit is based on a PC for the visual interface, parameter setting, and documentation of the process. For each furnace a hardware controller is used, which is directly communicating with the PC. This controller is regulating the carburising process independently from the PC, which means, if the PC has a shutdown, the controller is still regulating the carburising atmosphere. The regulation of the carbon potential is based on the signal from the oxygen probe, the temperature reading, and the CO level in the atmosphere. By using MFC technology in most cases it is sufficient to calculate the CO level from the flow rates of nitrogen and methanol. During the startup of the system the theoretical calculated CO level can be adjusted by correction parameters. This CO level is directly linked to the calculation of the carbon potential. Therefore, the real CO level is used for calculating and controlling the carburising atmosphere. However, in some cases it is recommended to install an additional CO analyser for controlling the CO level in the carburising atmosphere.



2 *Mass flow controller (MFC) technology*



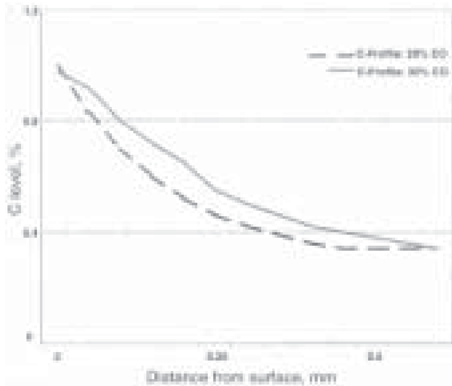
3 *PC program for accelerated carburising*

The CO level can be changed in the different steps of a carburising cycle, especially for the accelerated carburising process in addition to the carbon potential. An example is shown in Fig. 3. Here, the accelerated carburising process is implemented directly in the normal carburising program.

Benefits of accelerated carburising

Increased productivity by using higher CO levels has been discussed in several papers.[1,2,8] The benefits of accelerated carburising mainly depend on the required carburising depth. If the carburising depth is small, then the carburising cycle mainly depends on the deposition phase. As described above, this can be influenced by the atmosphere. So for a small carburising depth, a higher increase in productivity than for high carburising depths can be achieved, the latter requiring a longer diffusion phase.

Figure 4 shows the carburising profile of a typical carburising steel traditionally carburised for 180 min in 20%CO and carburised with the accelerated carburising process. The saving in the carburising time in this case was 15%.



4 *Carbon profile of carburised steel with 20%CO compared with carburised steel with 30%CO and 15% less carburising time*

In this example of continuous production over 6250h per year, accelerated carburising allows running up to 625 additionally charges. Savings up to 10% were also realised for carburising cycles of more than 5 h.[2,8]

Summary

Since manual blending panels have been used for setting up the appropriate atmosphere in the past, accelerated carburising technology based on higher CO levels during the deposition phase was not well implemented in the process. Reasons preventing higher CO levels included the higher cost of methanol compared to nitrogen, free production capacities, and high investment cost for automatic controlled blending panels. However, today, the situation has changed. Cost and quality is higher and production is at full capacity. Instead of investing in new furnaces, installing MFC technology can increase productivity by up to 20% and can help reduce the running costs. Furthermore, the accurate setting of the required flow rates allows part production with a very small tolerance in hardness. The PC technology allows running of different programs and provides reproducible carburising results. In addition, a data logging system is installed for the documentation of all important process parameters. As an option, a telemetry unit can be supplied, so that the system can be checked by Air Products over telephone lines; this allows rapid assistance with application based problems and in the case of troubleshooting. If a carbon controller already exists in the control system of the furnace, MFC technology can also be supplied independently. Accelerated carburising process (APS) technology can be realised with hardware links to the furnace control panel and comes equipped with all required safety features.

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