CARBOJET®
HIGH SPEED GASES IN HEAT TREATMENT FURNACES

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Abstract
In the heat treatment industry some types of furnace run without fans or with bad circulation of the protective atmosphere gas. As for most processes where there is an interaction between the load surfaces and the gas components, it is mandatory to ensure local gas exchange. CARBOJET® is a CFD optimised system which uses the free energy available from vaporising liquid nitrogen to carry out this task. The high nitrogen pressure available is utilised to drive a special designed injector inside the furnace. The increase in circulation achieved by this injection results in more uniformity and/or time saving in surface reactions like carburising.

Currently eight European heat treatment companies use CARBOJET® high speed gases in their roller hearth furnaces. In addition there are successful installations made in pit furnaces and rotary retort furnaces. This paper will review the fundamentals of this new high speed gas application and also enlighten the results from the latest customer installations

1. INTRODUCTION

In the area of protective-gas heat treatment, both furnaces with fans and furnaces without atmospheric circulation are used. Good exchange of gases directly at the surface of the component is necessary for most of the thermo-chemical processes to that place.

CARBOJET® is a CFD-optimised high-velocity gas-injection system with which this exchange can be achieved without additional expense of energy or elaborate modifications to the plant. In some cases, this technology, for which Linde Gas has applied for a patent, can replace existing fans.

In most heat-treatment plants, nitrogen at sufficiently high pressure is already available. With the specially designed nozzles installed inside the furnace, this pressure is optimally converted into powerful circulation. The examples of pit furnaces, rotary retort furnaces and roller-hearth furnaces show experience and results with the different heat-treatment processes, and the associated CFD calculations are presented. The introduction of this novel process technology has been continuously implemented in full-size production use since 2002.

2. THE CARBOJET® SYSTEM DESCRIPTION

The system consists of one or more CARBOJET® nozzles with piping, gas flow train and possible gas control system. By injecting small quantities of nitrogen at very high velocity (250...300 m/s) into specific areas of a furnace, CARBOJET® greatly improves the mixing of the furnaces gases, ensuring a homogeneous distribution of gas and temperature. The number of probes depends on the sizes and type of furnace, and on the existing gas demand. The probes can be operated either manually or by means of a CARBOFLEX® or CARBOTHAN® control units. The specially developed nozzles are
made of heat-resistant material to ensure a long lifetime. Linde offers customised solutions for each customer so that the systems are adapted to fit the individual requirements.

3. USING CARBOJET® IN PIT FURNACES

3.1 Objectives and benefits

In this case, the CARBOJET® technology is based on the use of a special nozzle built into the lid, together with the associated gas feeding system. The objectives of using this process in pit furnaces are the following:

- Savings on the fan and its operating costs
- Doing away with the lead cylinder
- Cost savings through simplified lid construction
- Greater plant availability through fewer down times
- Regular carburisation
- Reduced soot formation
- Better utilisation of the introduced reaction gases
- Avoidance of damage to furnace and batch through vibration
- Usability in all common heat-treatment processes

3.2 CFD modelling

Parallel to the practical tests, CFD calculations were carried out for a comparable pit furnace. The defined target parameter was the velocity field, as the measurement of the regularity of the carburisation of the components.

The geometry of the interior of the pit of the mathematical model, with a diameter of 9000 mm and a height of 2000 mm, was the same as that of the actual furnace used in the experimental phase. Even the speed of the fan, at 950 rpm, equalled the real value.

In the CFD model, the entry of a substance was defined that was already in the state of the furnace atmosphere, with a composition of (in Mol%): N₂ (40%), H₂ (40%) and CO (20%), and a comparable pulse intensity. Further framework data used were the operating temperature of 930°C, a pressure of 1 bar, and a C-level of Cp=1.00%. The model batch consisted of 3 layers of hanging rectangular blocks with dimensions of 50 x 100 x 400 mm, spaced 20 mm apart. For both the calculation and the test batches, this meant an extremely dense charge, which let relatively little gas through.

The following models were simulated:

- Furnace empty, with fan
- Furnace empty, with nozzle
- Furnace loaded, with fan
- Furnace loaded, with nozzle
- Furnace loaded, with fan and lead cylinder (gap 5.5 cm)

The results of the calculations of 3 selected models are shown in Figure 1. The calculation for operation with the fan shows a significantly less regular flow field around the components thus proving CARBOJET® to create better atmosphere conditions in this pit furnace.
3.3 Practical tests

After a first, successful pre-test, the next step was to carry out a comparative test with identical parameters. The charge (183 kg of forging scrap, shot-blasted, in C15, 300 x 140 x 1 mm) and test rings in 16MnCr5 (Ø 50 x 15 mm) were distributed on the various levels in a well-defined manner. The four temperature measurement points were positioned next to the test rings (Figures 2 and 3).
The parameters measured by the furnace controls, and also the pressures and flow volumes, were monitored regularly at the gas control panel. In addition, CO, CO₂, H₂ and CH₄ were measured by means of a gas analyser. The measurement data of the four thermo elements and those of CO and CO₂ were recorded with a data logger.

One batch was run conventionally, with the fan switched on and a standard nitrogen-methanol probe (as a reference batch). For the test batch, the fan was switched off and the CARBOJET® probe was put into operation. All media were now fed in through this. Neither of the batches was hardened, but rather cooled down to about 150°C with nitrogen. The samples were inspected in 0.1 mm sections by means of GDOS (Glow Discharge Optical Spectroscopy), see Figures 4 and 5.
When the measurement values are evaluated, it is obvious that the scatter is smaller in the case of the CARBOJET® test, showing that more regular carburisation took place compared with fan operation (Table 1).

Table 1. Standard deviation of carbon trends in the trials

<table>
<thead>
<tr>
<th>Depth mm</th>
<th>Fan</th>
<th>CARBOJET</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0,05</td>
<td>0,03</td>
</tr>
<tr>
<td>0,1</td>
<td>0,06</td>
<td>0,04</td>
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<tr>
<td>1</td>
<td>0,03</td>
<td>0,02</td>
</tr>
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</table>
The new technique made it possible to reduce the temperature differences within the batch. After the start-up phase of the controls, the difference was +/- 5°C with the fan, and +/- 1°C for the CARBOJET® test. The arrangement of the reference measuring points and the samples is shown in Figure 6.

![Figure 6: Position of reference points for temperature measurement](image)

The positive results of this comparative test convinced the customer to let Linde convert all their pit furnaces with the CARBOJET® technology. All the earlier mentioned objectives were reached. The fact that fans are no longer necessary creates considerable cost savings on service and maintenance. Because of the easy-to-assemble, low-maintenance technology of the CARBOJET® probes, only minimal down times occur for maintenance or exchange of the lid.

On top of the before mentioned benefits, it was possible to reach improved carburisation uniformity and more even temperature profile with CARBOJET®, both in the CFD calculations (Figure 1) and in the actual practice. As an additional benefit since the introduction of CARBOJET®, there have been no soot deposits on the upper baskets.

### 4. CARBOJET® INCREASES PRODUCTIVITY IN ROTARY RETORT FURNACES

As a rule, rotary retort furnaces (Figure 7) are used in heat treatment of small metal parts as an alternative to belt furnaces. In the application described here large numbers of electrical connectors are carbonitrided.

The objectives of use in the drum type furnace were the following:

- Improved mixing of the atmosphere (N₂ – methanol – natural gas – NH₃)
- As a result, improvement in control of the C level (O₂ probe)
- Minimisation of soft spot formation and/or increase of throughput
When agreeing on the procedure, it was arranged with the customer to replace the existing CARBOTHAN® probe (nitrogen – methanol) with a CARBOJET® nozzle at the same position in the entrance area of the furnace. All process values and gassing quantities were to remain unchanged.

Shortly after the commissioning, it was seen that it was possible to increase the throughput of the plant by an initial 18%. This resulted in increasing the revs of the retort and the amount of parts per fed to the furnace per loading. It was further possible to decrease the scatter of the hardening values, compared with the original state. At present, the limiting factor in the plants is the goods transportation system. For this reason, they are being operated with a performance increase of only 10%. The greater increase in performance is to be reckoned with when the goods removal system has been optimised. Because no modifications for the furnaces were needed, it was possible to implement the process successfully on all three existing rotary retort furnaces at the plant within half a year.

4. USE IN ROLLER HEARTH FURNACES IN THE TUBE INDUSTRY

For many years, roller hearth furnaces have been in widespread use in the steel tube industry, where they are used for the most varied annealing processes, from tempering to carburisation. As a rule, these annealing processes are carried out in protective gases, such as endothermic atmosphere, nitrogen, exothermic atmosphere or monogas, or mixtures of these.

In general, the operation of these furnaces is characterised by very low gas-flow velocities (for the most part < 0.2 m/s). The demands on the results of the annealing process have tremendously increased. For example the decarburisation of the tubes is not anymore allowed by the customers who are using the tubes in demanding constructions in automotive or construction industry. This has also increased the demands for the protective gas atmosphere.

But even the use of a heavily reduced protective gas can sometimes lead to unsatisfactory results with regard to the regularity of the carbon content in the surface of the pipe, because the low flow velocities may make the distribution of the active gas components within the furnace space irregular. This can also lead to increased formation of soot. The low flow velocities and the lack of circulation also make exact metering of processes that take place immediately under the surface more difficult. This is mainly due to the relatively large volume of the furnace, which is measured at only a few, non-representative points. To permit a maximum flexibility in the tube production, it should be possible to change between different atmospheric settings as quickly as possible, so as to minimise or totally avoid stoppage times.

The main objectives of using CARBOJET® in roller hearth furnaces can be formulated as follows:

- Quicker change of atmosphere when changing the type of steel
- More regular distribution of carbon over the circumference of the pipe
- Better burning off of drawing-compound residue in the front area of the furnace, to minimise the formation of delta-ferrite in the seam
- Better utilisation of the introduced reactive gases
- Less soot formation
- Higher carbon level
- Improved transfer of carbon to the surface of the material

5. PROCESS IMPROVEMENT THROUGH HIGH-VELOCITY GAS INJECTION

The weak points described above can be remedied or minimised by using several high-velocity injection probes mounted at various points in the furnace. In the furnace system described here, endothermic atmosphere is blown into the latter third of the furnace, in the area of the maximum annealing temperature. At the furnace exit and in the cooling section, nitrogen is introduced as a seal gas to concentrate the active components of the protective gas in the furnace space. The quantities of protective gas used, relative to the total volume, permit only 2.5 exchanges of gas per hour.
It has been shown that a higher flow velocity leads to improved material exchange, both within the atmosphere and between the atmosphere and the surface of the material. From a cost point of view, it is not possible to provide increased circulation in the furnace space by increasing the quantity of protective gas. On the other hand, the use of small quantities of the nitrogen that is fed to the furnace anyway to operate four CARBOJET® nozzles leads to an adequate increase in the circulation of the gas. Experience with the eight roller hearth furnaces in Europe now fitted with CARBOJET® confirm these positive results.

6. CFD MODELLING OF ROLLER HEARTH FURNACES

As part of a development project, the comparative calculation of a complete roller hearth furnace was carried out with the FLUENT® software. All essential elements, such as steel tubes, conveyor rollers and furnace and cooling sections, were accounted for in the 2.2 million cells of the model. The radiant tubes were assumed to be a homogeneous, partially porous layer with an opening of 20% of the surface. Calculations for operation with and without CARBOJET® nozzles were carried out at constant gas quantities and temperature conditions. Gas velocity is to be seen clearly only in the endothermic-atmosphere injection zones (Figure 8, top). Figure 8 (bottom) makes it clear that the overall gas velocities are significantly higher with the new nozzle technology. The overall consumption of gas is the same in both simulations.

Figure 8. CFD model of gas velocities (m/s) in the endogas injection zone in a roller hearth furnace

The improved homogeneity of the atmosphere in the furnace, which was already observed in practical use, was easily demonstrated by the calculations. Very close to the position of the pipe (5 cm above the material), flow velocities that were on average 5 to 6 times higher were ascertained.

A CFD calculation that was carried out separately led to optimisation of the nozzle geometry, which can achieve a maximum of movement in the atmosphere of the furnace with a minimum quantity of nitrogen. A patent for the CARBOJET® technology has applied.