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HIGH SPEED GASES IN HEAT TREATMENT FURNACES[1]

Christoph Laumen[2]
Sylvano Bigio[3]
Gerd Waning[4]

Abstract

In the field of heat treatment with protective atmosphere, many furnaces are operated with fans and without atmosphere circulation. For most of the thermo-chemical processes which take place here, a good gas exchange in the immediate vicinity of the component surface is essential. CARBOJET® is a CFD optimised high velocity gas injection system with which this exchange can be implemented without additional energy or involved system modifications. The technology, for which Linde Gas has submitted a patent application, can partly replace existing fans. In most heat treatment facilities, nitrogen is already available at a sufficiently high pressure. In an optimised process, this pressure is converted to produce a strong circulation in the furnace using specially designed jets. This article will describe the experiences and results which were ascertained for different heat treatment processes based on example applications in pit, rotary retort and roller hearth furnaces; related CFD calculations will also be discussed. Since its launch, this novel process technology has been continuously developed, directly in existing production facilities and, at the same time, optimised with the aid of CFD calculation methods.

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2 *The Linde Group, Unterschleissheim, Germany. christoph.laumen@linde-gas.com.*
3 *Linde Gas, Sao Paulo, Brazil. Sylvano.Bigio@br.aga.com.*
4 *Linde AG, Gases Division, Bielefeld, Germany. gerd.waning@de.linde-gas.com.*

1 SYSTEM DESCRIPTION

The system consists of one or more injection lances with piping and a flow train. By injecting small quantities of nitrogen into individual areas of a furnace at high speeds (250-300 m/s), the injectors create a blending in the furnace gas which ensures a homogenous gas and temperature distribution. The number of lances depends on the type and size of the furnace and the current gas requirement. The lances can be operated either manually or with the help of a CARBOFLEX® control unit. The lances, which have been specially developed for this purpose, are made from a heat-resistant material in order to ensure a long service life. Each customer is offered tailored solutions in which the injection systems are adapted to individual requirements.

2 APPLICATION IN THE POT FURNACE AS AN ALTERNATIVE TO FANS

The feed technology consists of a special lance mounted in the lid and the associated gas delivery system. The following objectives should be achieved with the use of injection technology in the pot furnace:

- Saving with regard to the fan and its operating costs.
- Omission of the guide cylinder.
- Cost saving due to simplified lid design.
- Greater system availability due to reduced downtime.
- More consistent carburisation.
- Less build-up of soot.
- Improved utilisation of the delivered reactive gases.
- Avoidance of vibration damage to the furnace and batch.
- Potential for application in all conventional heat treatment processes.

3 CFD SIMULATION FOR POT FURNACES

Alongside the practical tests, various CFD calculations were carried out for a comparable pot furnace. The velocity field was defined as a measure for the consistency of the carburisation of the components.

At a diameter of 900 mm and a height of 2000 mm, the geometry of the pot furnace interior used in the calculation model corresponded to the actual furnace geometry used in the test phase. At 950 revolutions per minute, the fan speed also corresponded to the real value.

In the CFD model, the addition of a material consistent with the furnace atmosphere was defined with the following composition (Mol %): N_2 (40%), H_2 (40%), CO (20%) with comparable pulse intensity.

Other underlying conditions included an operating temperature of 930 °C, a pressure of 1 bar and a C level of Cp = 1.00% C. The model batch consisted of three levels of hanging cuboids with a cross-section of 50 mm x 100 mm x 400 mm, 20 mm apart. This meant that an extremely tight loading, which was therefore relatively poorly permeable to gas, had been chosen for both the calculation and the test batches (Figure 1). The following models were simulated:

- Furnace empty with fan.
- Furnace empty with injector.
- Furnace loaded with fan.
- Furnace loaded with injector.
- Furnace loaded with fan and guide cylinder (gap 5.5 cm).

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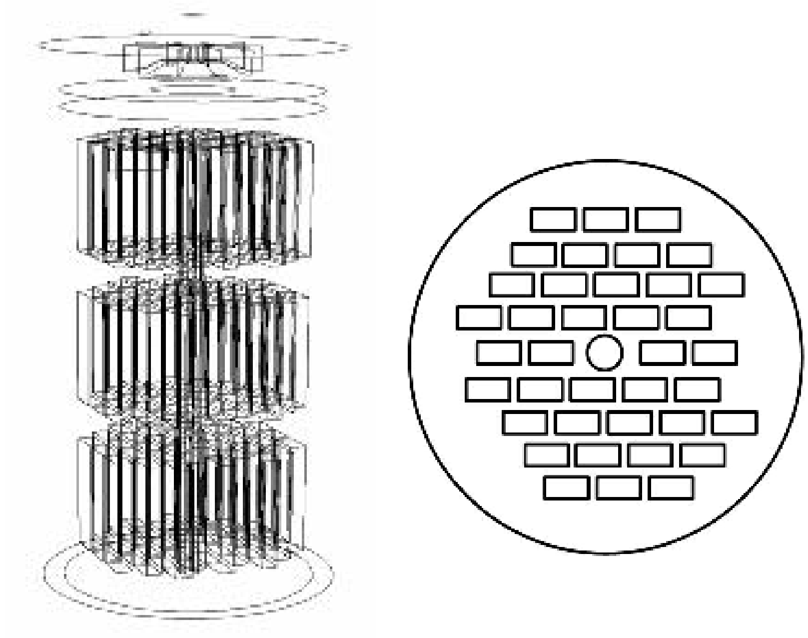

Figure 1. Side view and top view of model Charge.

The calculation results for three selected models are shown in Figure 2.

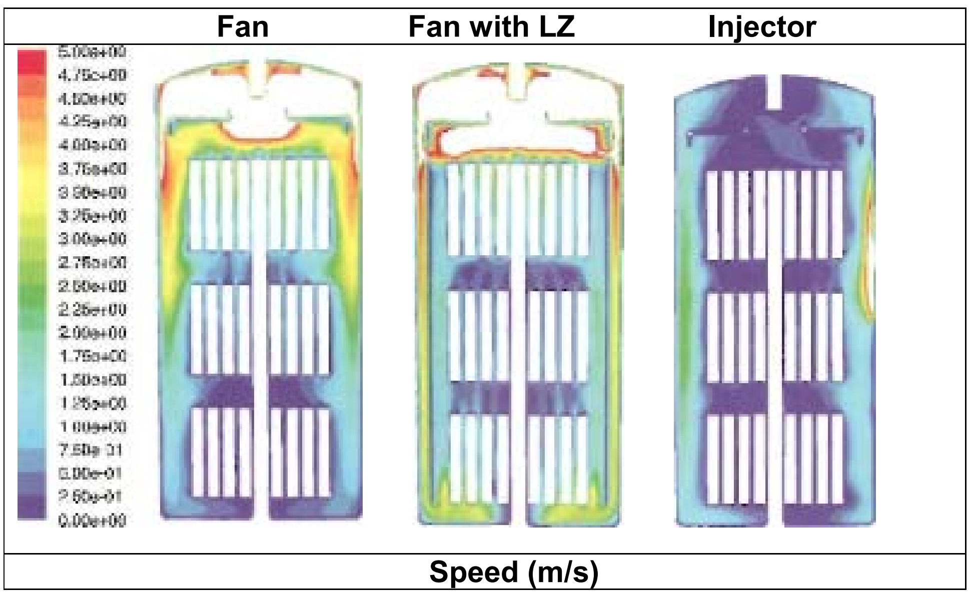

Figure 2. CFD vector field in a pit furnace (D 900 mm, H 2000 mm); the Simulation calculation for the process with fan in Operation shows a much more inhomogeneous flow field.

4 COMPARISON TEST WITH TWO IDENTICAL BATCHES

Following an initial, positive preliminary trial, the next step saw a comparative trial using identical parameters, which was carried out systematically: load [183 kg (forge residue) shot-blasted, made from C15, 300 mm x 140 mm x 14 mm] and sample rings made from 16MnCr5 (Ø50 mm x 15 mm) were defined and distributed to the different levels. Similarly, four temperature reference measuring points were set within the sample rings (Figures 3 and 4).

Figure 3. Pit furnace with reference charge.

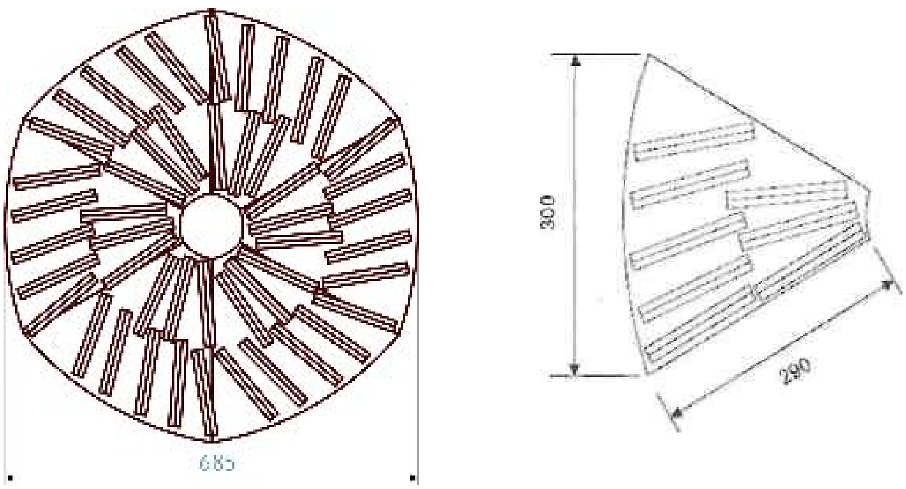

Figure 4. Allocation of ballast, 288 pieces of ballast, 0.635 kg each, total of 183 kg.

The parameters measured by the furnace control unit and the pressures and flow rates at the gas control panel were monitored on a regular basis. In addition, a gas analyser was used to measure CO, C02, H2 and CH4. The performance data of the four thermal elements and of the CO and C02 were recorded using a line recorder.

A batch was driven conventionally with a switched-on fan and a standard nitrogen methanol lance (reference batch). The fan was switched off for the test batch and the CARBOJET® lance operated. All media were now fed in accordingly.

Neither batch was hardened, but both were cooled to approx. 150 °C under nitrogen. The samples were examined using GDOS (Glow Discharge Optical Spectroscopy) analysis in 0.1 mm steps (Figures 5 and 6). When looking at the readings it is apparent that the distribution of the values is less in the case of the trial using the high-velocity injection, and therefore the carburisation was more consistent when compared with fan operation (Table 1). The differences in temperature within the batch were reduced when using the new technology. After engaging the regulation with the fan they were ± 5 °C, while in the test using the new injection technology they were ± 1 °C.

As a result of the positive results of this comparative test, the user has converted all of its pot furnaces to the new injector technology. The targets described above were achieved. As fans are no longer necessary, there are considerable cost savings in terms of maintenance and repairs.

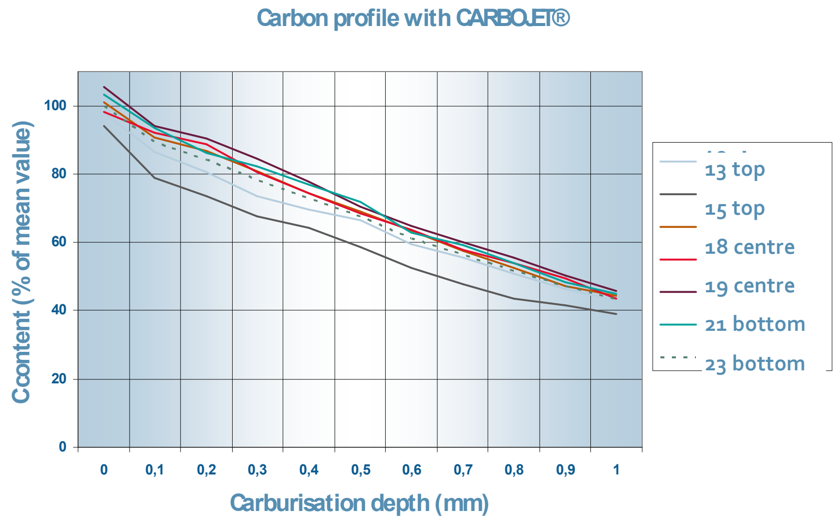

Figure 5. Carbon depth profile in 16MnCr5 test samples in process with CARBOJET®, analysed by GDOS.

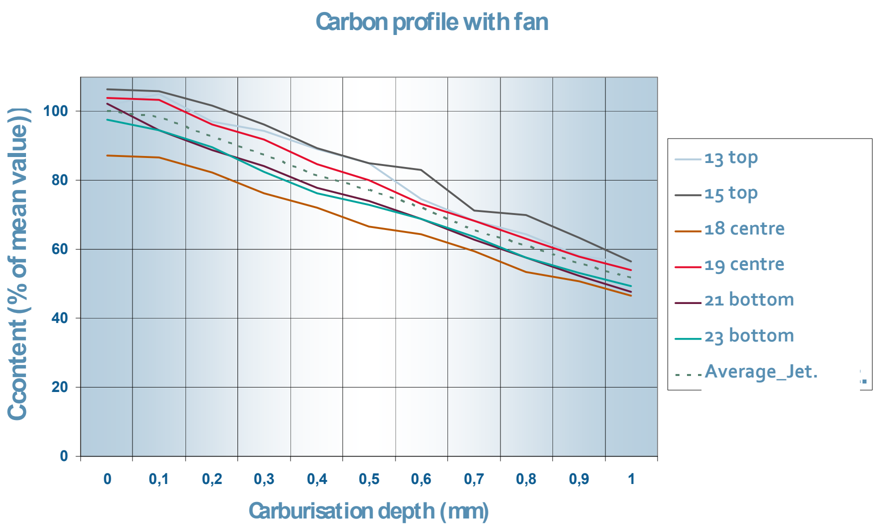

Figure 6. Carbon depth profile in 16MnCr5 test samples in process with fan, analysed by GDOS.

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Table 1. Standard deviation of carbon trends

Depth (mm)	Standard Deviation	
	With fan	with CARBOJET®
0	0,05	0,03
0,1	0,06	0,04
0,2	0,05	0,05
0,3	0,06	0,05
0,4	0,06	0,04
0,5	0,06	0,04
0,6	0,05	0,03
0,7	0,03	0,03
0,8	0,05	0,03
0,9	0,04	0,02
1	0,03	0,02
Average	0,049	0,035

Because the lance technology is assembly-friendly and low-maintenance, only minimal downtimes for maintenance or replacement of lids are necessary. Moreover, improved consistency of carburisation and temperatures was evident in both the CFD calculations (Figure 2) and the practical application. Soot is no longer deposited on the upper cages since the introduction of the new injection technology. Figures 7 and 8 show the practical results for gear wheels used in wind energy plant engineering. Here it was possible to remove the guide cylinder used earlier without having to replace it.

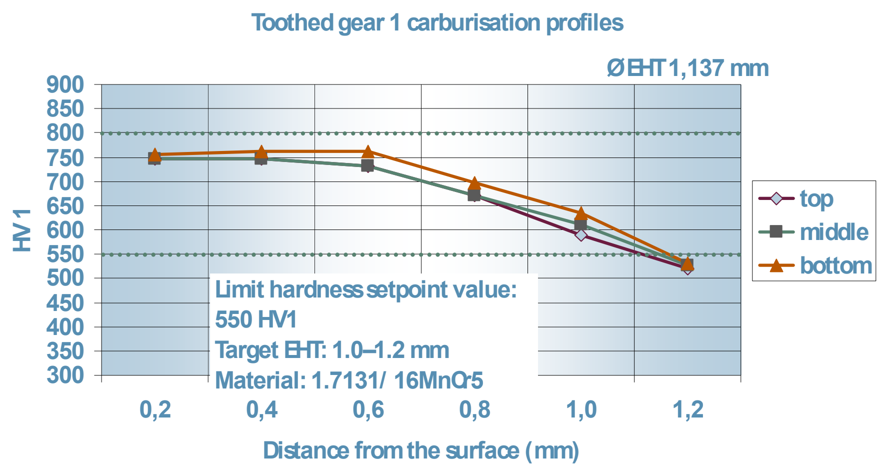

Figure 7. Practical results for carburizing depth 1.0-1.2 mm.

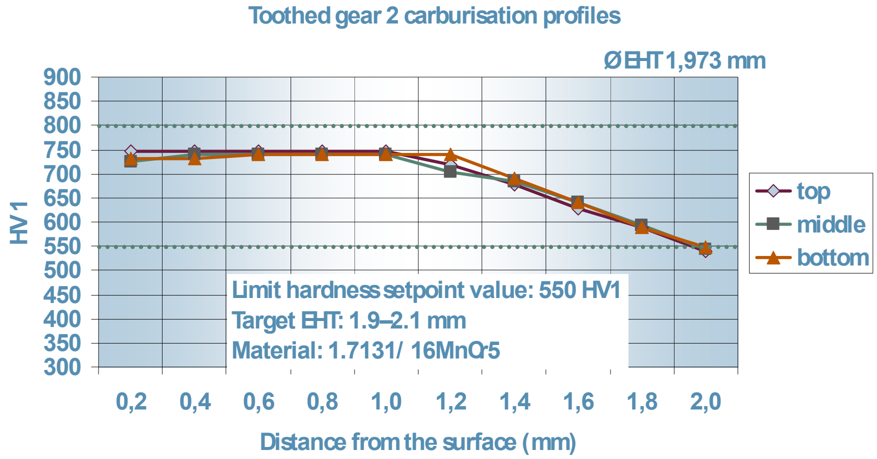

Figure 8. Practical results for carburizing depth 1.9-2.1 mm.

5 APPLICATION OF CARBOJET® IN THE ROTARY RETORT FURNACE TO INCREASE PRODUCTIVITY

Rotary furnaces (Figure 9) are generally used as an alternative to conveyor furnaces for the heat treatment of bulk goods. In a given application, large quantities of so-called "tensile proving rings", which are used in the field of electrical joining techniques, are carbonitrided.

Figure 9. Rotary retort furnace.

The following objectives should be achieved by using the new technology in the rotary retort furnace:

- Improved blending of the atmosphere (N2 – methanol – natural gas).
- As a result, an improvement of the controllability of the C level (02 – probe).
- Minimisation of soft spot formation and/or an increase in throughput.

When co-ordinating the procedure, an agreement was entered into with the customer on an exchange of the proven nitrogen methanol injection lances for a CARBOJET® lance at the same position in the inlet area of the furnace.

All process values and gassing quantities should be kept unchanged.

Soon after commissioning it was found that it was possible to increase the system throughput initially by up to 18% by increasing the retort speed and quantity of parts per charging process. It was possible to further minimise the distribution of the hardness values compared with the original status. At present the handling system is a limiting factor. For this reason, the effective increase in performance is just 10%. A higher increase in performance is expected after the handling system has been optimised. Because of its simplicity, the procedure was successfully implemented in all of the company's existing rotary scroll furnace systems within six months.

6 APPLICATION IN CONTINUOUS ROLLER-HEARTH FURNACES IN THE SEMI-FINISHED PRODUCTS INDUSTRY

Continuous roller-hearth furnaces have been widely used in the steel pipe industry for many years. Within this industry, they are used for a broad range of annealing processes from tempering to carburisation. As a rule, these annealing processes are carried out under protective furnace gases such as endothermic atmosphere, nitrogen, exothermic atmosphere or monogas, or even mixtures of them. Generally speaking, operation of these furnaces is characterised by very low gas flow speeds (in most instances < 0.2 m/s). As a result of the increase in recent years in the requirements for the result of the annealing process in respect of unchanged carbon content in the direct vicinity of the surface, compared with merely an annealed, decarbonised pipe, as was previously the norm, so the requirements for the protective furnace gases used have increased.

But even the use of a sharply reducing protective furnace gas can occasionally produce unsatisfactory results in respect of the consistency of the carbon content in the pipe surface; this is because, as a result of the low flow speeds, the distribution of the active gas components within the furnace chamber can be inconsistent, which, amongst other things, can also lead to an increased build-up of soot. The low flow speeds and the lack of circulation make it more difficult, amongst other things, to record the processes taking place in the immediate vicinity of the surface with accuracy using measuring technology, as measurement of the relatively large furnace volume occurs at only a few, mostly non-representative, measuring points.

In order to afford production as much flexibility as possible, it should be possible to switch between different atmospheric settings very quickly in order to minimise idling times or even avoid them altogether.

Among others, the following objectives can be formulated for use of the new type of high-speed injection technology in the roller hearth furnace:

- Faster change of atmosphere when the steel type changes.
- More consistent carbon distribution on the perimeter of the pipes.
- Better burning off of drawing agent residues in the front area of the furnace to minimise the formation of delta ferrite.
- Improved utilisation of the delivered reactive gases.
- Less build-up of soot.
- Achievement of higher carbon levels.
- Improved carbon transfer on the surface of the material

7 IMPROVED PROCESS THROUGH HIGH-SPEED GAS INJECTION

The weaknesses described above can be removed or minimised by using multiple high-speed gas injection lances fitted in the furnace. In the furnace system described here, the endothermic atmosphere in the rear third of the furnace, in the area of the maximum annealing temperature, is blown into the furnace chamber. Nitrogen is input as a sealing gas at the furnace inlet in the cooling section to concentrate the active components of the protective furnace gas in the furnace chamber. The quantities of protective furnace gas used, relative to the total volume, only permit around 2.5 gas changes per hour. A higher flow speed demonstrably leads to an improved exchange of material both within the atmosphere and between the atmosphere and the material surface. From the cost perspective, it is not possible to ensure increased circulation in the furnace chamber by increasing the quantity of protective furnace gas. On the other hand, the use of small quantities of nitrogen already fed into the furnace for the operation of four injectors produces an adequate increase in the recirculation of the gas. These positive results are borne out by the experiences at the continuous roller-hearth furnace plants in Europe that are equipped with the procedure and of which there are now seven.

8 CFD MODEL FOR CALCULATING THE FLOW CONDITIONS IN THE CONTINUOUS ROLLER-HEARTH FURNACE

As part of a development project, a comparative CFD calculation of a complete continuous roller-hearth furnace was carried out using the FLUENT® software. All of the important elements such as steel pipes, transport rollers, furnace and cooling section walls etc. were taken into consideration in the model's 2.2 million cells. The pipes to be annealed were accepted as a homogenous, semi-transparent layer with an opening of 20 % of the area. Under conditions of a constant quantity of gas and a constant temperature, the calculation was carried out for operation with and without CARBOJET® injectors (Figure 10). The improved homogeneity of the furnace atmosphere already found in the practical application was readily demonstrated by the calculation. A flow speed was determined which, on average, is 5 to 6 times higher in the immediate vicinity of the pipe (5 cm above the material).

A separate CFD calculation produced optimised injector geometry with which maximum movement in the furnace atmosphere can be realised with minimal use of nitrogen.

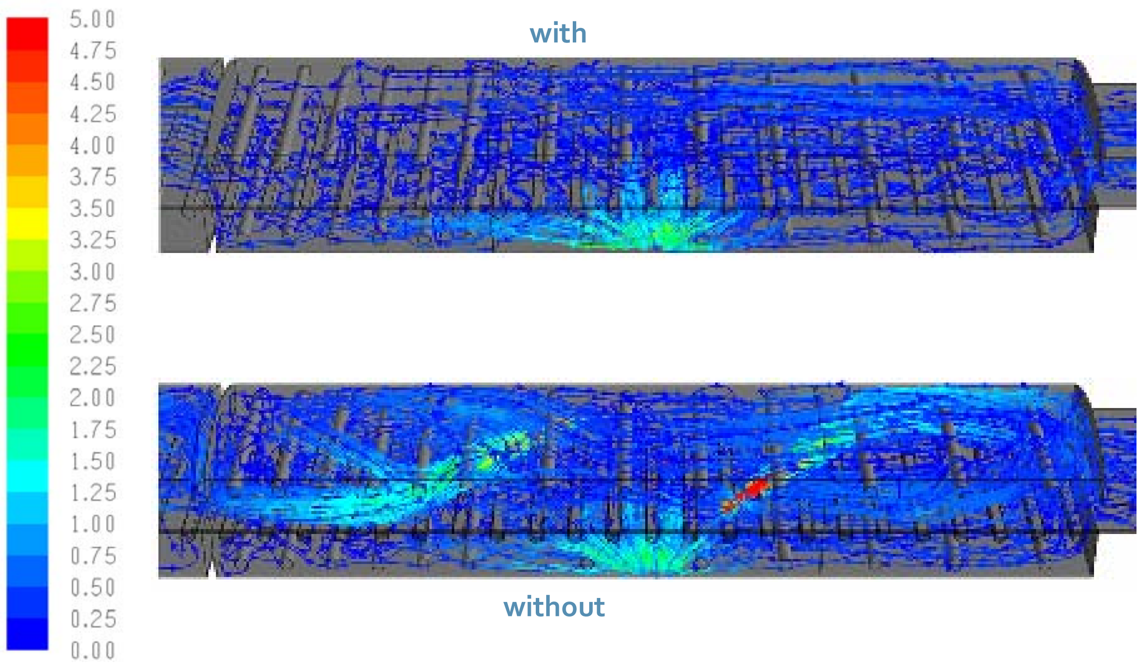

Figure 10. a) Gas velocity (m/s) in the zone of endogas injection into a roller hearth furnace. The main velocity is relatively low. A definite increase can be shown at the endogas inlet only. b) Gas velocity (m/s) in the zone of endogas injection into a roller hearth furnace with 2 CARBOJET®-lances. The total gas velocity is significantly higher whereas the red colour stands for particularly high values. The total gas consumption is equal for both simulations.

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9 SUMMARY

The newly developed high-speed gas injection technology provides the person carrying out the heat treatment with a new, additional, individually usable tool. This enables him, depending on the usage, to minimise atmospheric in homogeneities at existing furnace plants, and to waive fans should the need arise without making quality reductions or increasing the performance of existing plants. Maintenance and repair costs are reduced. As a rule, the technology can be integrated into existing plants at little expense and without the need for additional consumption of protective furnace gas. Both the reliability of the process and the reproducibility of the results of the heat treatment are improved.