A CONCEPT FOR FASTER CARBURIZING IN CONTINUOUS FURNACES

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ABSTRACT

An atmosphere control system for a continuous carburizing pusher furnace has been developed. The atmosphere system is based on nitrogen/methanol with propane and water as additional gases for carbon potential control. It enables independent carbon potential control per furnace zone, which was not possible with the old control system. Important parameters for good results are proper location of gas and methanol inlets, the design of gas injection installations and the control system with gas and methanol flow control and related software. It was found that in order to reach a good atmosphere controllability it was necessary to install and use an oxygen probe for carbon potential control in the final diffusion zone. Still the existing CO_2 carbon potential control was used in the carburizing zone. The system has been in production since beginning of 1997 and has given a productivity increase of the order of 15%. If there is no need for productivity increase it is possible to lower the carburizing temperature and still have the same output with the additional benefit of a lower running cost for the furnace. It is the experience that surfaces are cleaner after carburizing with the new system.

1. INTRODUCTION

A carburizing recipe should have a high carbon potential in the beginning and a lower carbon potential at the end of the process cycle if it is the goal to achieve the shortest carburizing time. This can easily be realised in a batch furnace by changing from a high carbon potential used during boost to a lower carbon potential during final diffusion. To run boost carburizing in a continuous pusher furnace, without sealing doors between different sections, is, however, not equally straight forward. It was the task to develop a gas system and a control scheme for faster carburizing in such a continuous furnace case. An additional purpose has been to improve quality in the carburizing process.

For efficient carburizing the carbon potential must be controlled locally in each zone. Two facts counteract a successful realisation of this possibility. First there is almost complete mixing of the atmosphere all along the furnace length. It is therefore difficult to achieve any major atmosphere composition variation along the furnace. Secondly, the carbon potential decreases with increased temperature for a fixed atmosphere composition. The temperature is high, typically 900-950^{o}C, in the first part of the pusher furnace but low, 860^{o}C, in the last part of the furnace. The carbon potential in the diffusion zone must be controlled to the level that gives required final surface properties, typically 0,8-0,9%C. The temperature influence on the carbon potential then accordingly results in a too low carbon potential in the high temperature carburizing zones, which is opposite to the conditions that make carburizing time as short as possible.

2. SIMULATION OF CARBURIZING

A carburizing simulation program called CCALC developed by AGA AB was used to simulate carburizing and resulting carbon concentration profiles. CCALC is a PC simulation program that fed with furnace recipe (atmosphere composition, carbon potential and temperature), object dimension and steel composition, calculates the resulting carbon profile. In order to reach agreement between calculated and measured results the proper carbon mass transfer coefficient first had to be determined. By introducing a correction factor, f, for the mass transfer coefficient, k', in the C-CCALC program the calculation results agreed with practical results from the furnace.

The carbon mass flux, J_c, from the gas to the steel surface is then expressed as,

$$J_c = f\,k'(u_s - u_g)$$

k′ is the mass transfer coefficient according to Collin [1] which is dependent on temperature and furnace gas composition. u_s is the surface carbon content and u_g the furnace atmosphere carbon concentration.

For the original carbon potential and temperature variations the calculated carbon and experimentally measured concentration profiles are shown in figure 1.

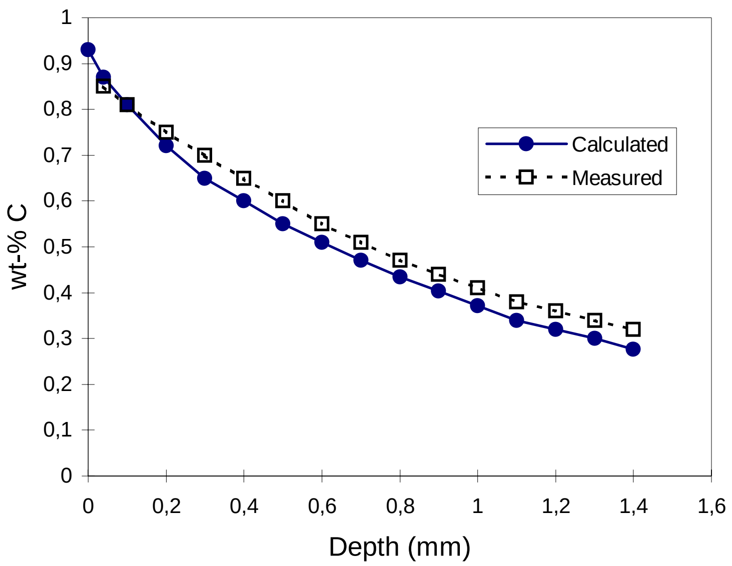

Figure 1: Calculated carbon concentration profile when using the original atmosphere carbon potential control system.

3. ATMOSPHERE AND CARBON POTENTIAL CONTROL

The existing atmosphere system at the customer is based on nitrogen/methanol. An initial idea was to create a gradient of CO and H_2 along the furnace by adding most methanol in the beginning of the furnace. This turned out to yield only a difference of about 1 vol%CO between maximum and minimum concentrations. It shows that the gases mix almost completely along the furnace.

Propane is used as enriching gas to increase the carbon potential. To enable individual carbon potential in the diffusion zone it was required to find a gas that gives the possibility also to decrease the carbon potential Air, carbon dioxide and water are possible additions. Water was chosen in this case as it will directly influence the fast reaction,

$CO+H_2=C+H_2O$

which controls the carbon potential.

By adding water it was possible to reach a smaller carbon potential difference between the high temperature zones and the low temperature diffusion zone as compared to the old system.

It was also necessary to choose the best analysis method to measure and control the carbon potential in the diffusion zone. The alternatives were CO_2 infra red analysis, dewpoint measurement and oxygen measurement with an oxygen probe. The carbon potential control respectively is based on one of the following relations,

$$a_C = K \times \frac{p_{CO}{}^2}{P_{CO_2}} \qquad (1)$$

$$a_C = \frac{K \times p_{CO} \times p_{H_2}}{p_{H_2O}} \qquad (2)$$

$$a_C = K \times \frac{p_{CO}}{p^{1/2}{}_{O_2}} \qquad (3)$$

With varying CO-content it is necessary also to measure the CO-level for accurate carbon potential control.

By adding a gas into the diffusion zone a non equilibrium situation is created. In a non equilibrium atmosphere there is always a small error between the measured and the real carbon potential. By real is meant the carbon concentration obtained in iron foils. It was found that control with an oxygen probe gave good agreement with actual carbon analysis on foils and on cylindrical turning samples. Carbon potential evaluated from CO_2 analysis gave, however, too high carbon potentials. Figure 2 shows the difference in carbon potential evaluated from CO_2 and oxygen probe measurements in the diffusion zone. During the analysis time the mean carbon potential values were in this case 1,30%C and 1,02%C evaluated from CO_2 and oxygen probe respectively, thus a difference of approximately 0,3%C.

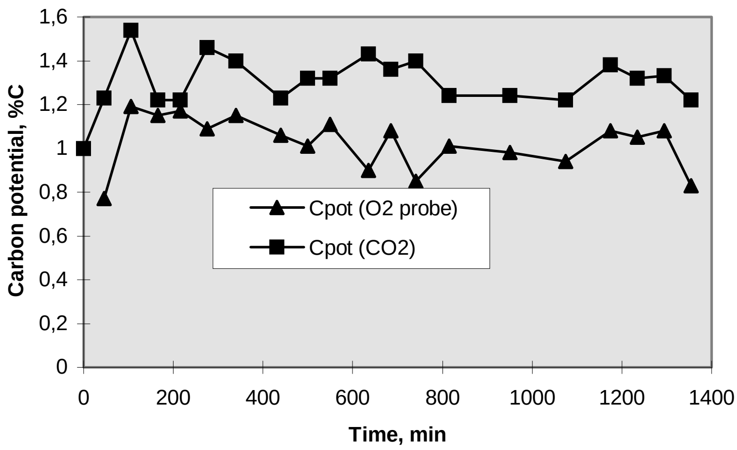

Figure 2: Carbon potentials evaluated from CO_2 and oxygen probe analysis in the diffusion zone of the pusher furnace.

Considering these results it was decided to use and install an oxygen probe in the diffusion zone.

There were originally four different gas/methanol inlets to the furnace. When water was added to the diffusion zone it was important to restrict the effect just to the diffusion zone. This was fulfilled by establishing the right flow directions in the furnace. The methanol inlet in the diffusion zone was taken away and just nitrogen was introduced there in addition to the water. To keep the overall same nitrogen/methanol proportions, accordingly, more methanol was introduced in the first zones. A precondition was that the total amount of gas should not exceed what was earlier used, 35 m^3/h.

A control system has been developed for the on line closed loop carbon potential and atmosphere control. It uses the existing CO_2 carbon potential control in the carburizing zones. Also CO analysis is made for accurate control. The system contains:
-1) a gas sampling system with scanner, for changing from one sampling port to another
-2) an IR analyser for CO and CO_2
-3) the oxygen probe
-4)a mixing and flow station for gases and methanol and
-5)a PLC programmed with required soft ware for signal handling and control.
The temperature in the different zones is an additional input signal. A further ongoing development is the connection of the system to a central computer. Recipe handling and data logging are performed on that computer. The system is illustrated in figure 3.

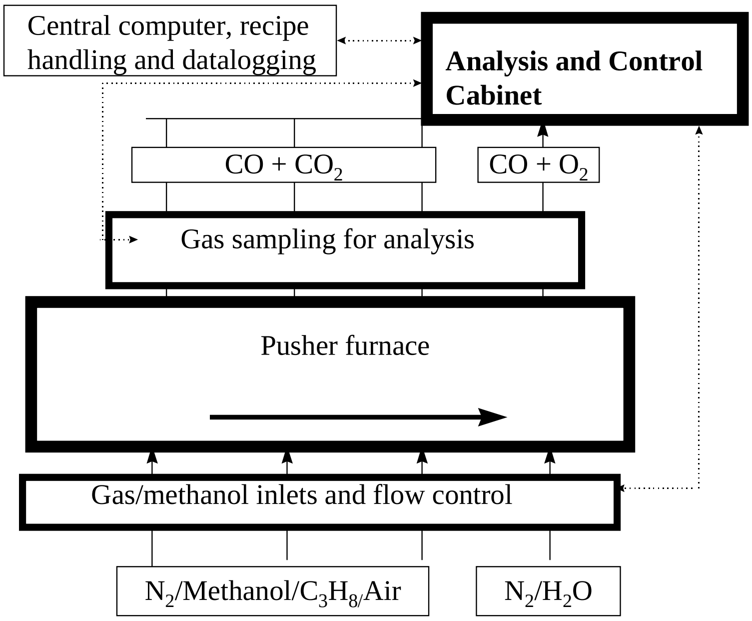

Figure 3: The principal design of the atmosphere control system.

A number of test runs were made with the purpose to reach an optimum carbon potential variation between carburizing and diffusion zones.

4. RESULTS

CCALC was used to simulate the result of different carbon potential profiles along the furnace and then these recipes were realised in practical carburizing runs. The fastest carburizing recipes, which had a potential to increase carburizing rate by approximately 30%, could be realised atmosphere wise but there was a limit set by other furnace functions primarily the heating system. This limit corresponded to a 15 % increase in carburizing rate. Therefore the carbon potential variations were chosen not only to give the fastest carburizing but also to give a good safety margin to avoid sooting. Figures 4-5 show the temperature-time and carbon potential-time recipes for the original setting and after installation of the new control system. (The carbon potentials and temperatures were actually measured in four points of the furnace so the figures 4-5 are somewhat idealised.) The time scale in the figures correspond to a certain length into the furnace and the total time corresponds to the total length of the furnace. Both recipes gave about the same carburizing depth. From the figures is evident that a time saving of approximately 100 minutes, corresponding to approximately 15% has been reached. This is a result of that the carbon potential has been increased in the carburizing zone and decreased in the diffusion zone.

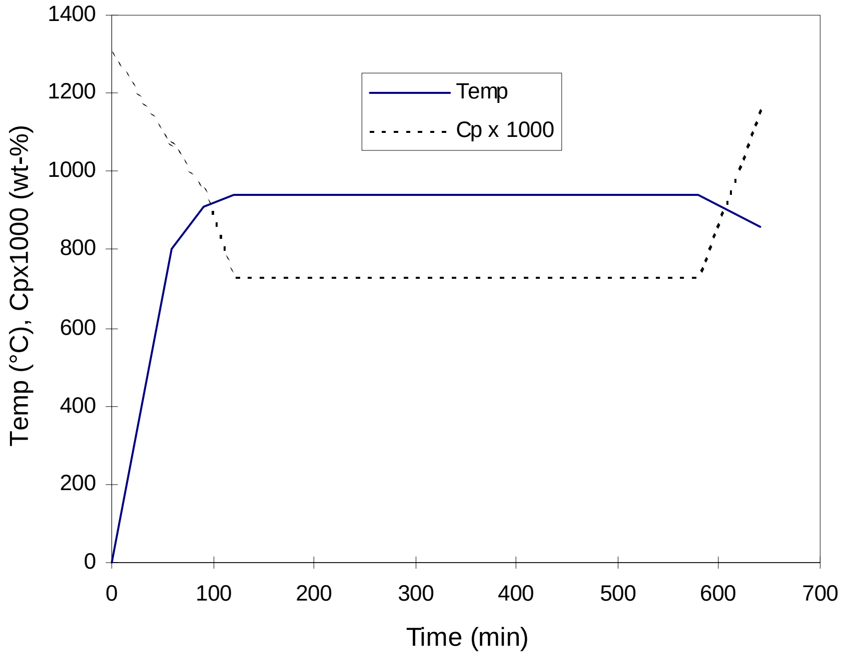

Figure 4: Carbon potential, C_p, temperature and time needed with the normal carburizing cycle

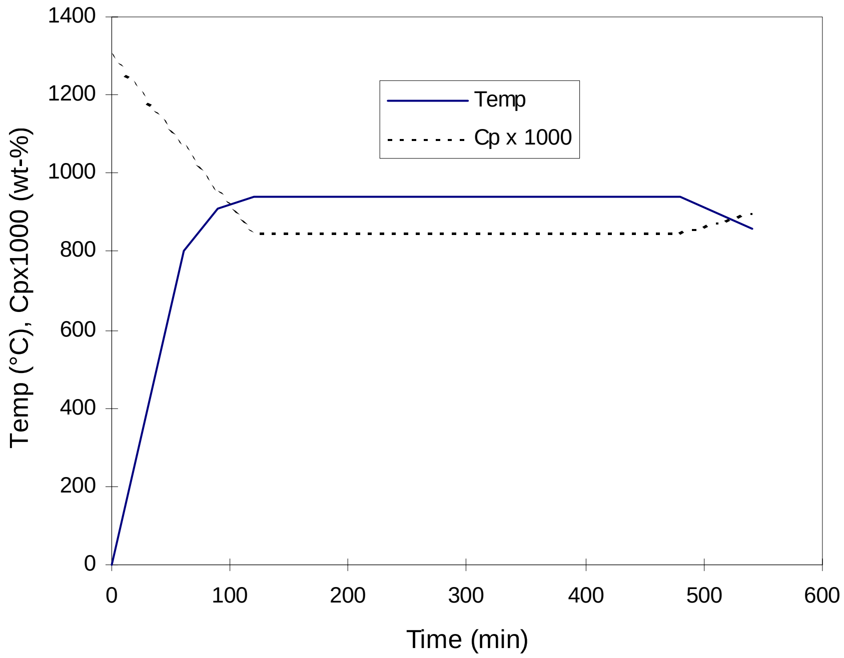

Figure 5: Carbon potential, C_p , temperature and time needed with the new atmosphere control system

The resulting carbon concentration curve is less step than before, see figure 6, which shows calculated and actually analysed carbon concentrations.

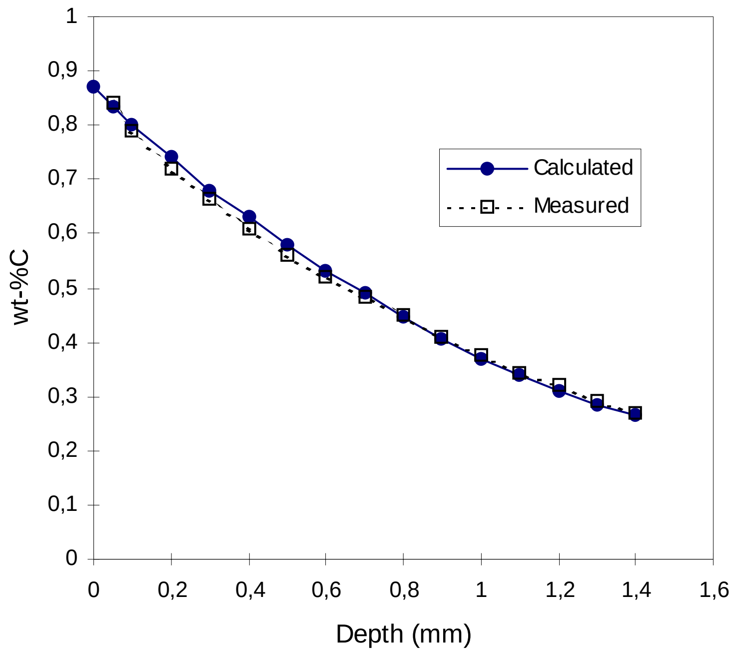

Figure 6: Calculated and measured carbon concentration profile with the new carburizing recipe

Hardness and case depth were measured both on test bars and on gears. Table 1 summarises results for carbon concentrations and case depths measured during the test period. The results in table 1 cover both measurements on gears and on cylindrical test bars.

Table 1: Results for test bars and gears

		Turning sample ∅25x120 mm			**Gear**	
		Surface carbon at 0,04mm, %C	**Depth to 0,4%C, mm**	**DC, mm**	**DC_{root}, mm (gear)**	**DC_{flank}, mm (gear)**
Reference	Mean	0,83	1,00	1,26	1,00	1,22
	Std. Dev.	0,024	0,054	0,10	0,090	0,090
New cycle	Mean	0,82	0,96	1,25	1,02	1,24
	Std.dev.	0,018	0,013	0,06	0,100	0,090

Note: DC is the case depth to 550HV

The depth of internal oxidation was also measured and found to be equal or less for the new cycle compared to the reference case.

The development and installation of the atmosphere control system has generally improved the carbon potential control. Reasons are that: 1) the CO concentration is measured and taken into account for carbon potential control, 2) the local temperature at the analysing point is used and 3) the carbon potential is separately controlled in the diffusion zone. There is a potential to run with higher carbon potentials without the risk of sooting although this was not utilised fully by the customer for the reason explained earlier. Another benefit to be utilised is the possibility to lower the surface carbon concentration in order to lower the amount of retained austenite. It is the experience that surfaces are cleaner after carburizing with the new system, which in turn improves the quenching oil cleanliness. The scatter in obtained hardness and case depths tend to be improved but this must be confirmed by more tests.

In cases where there is no need for higher production rate it is possible to utilise the control system in order to lower the furnace temperature still maintaining the same productivity. A lower furnace temperature would decrease maintenance costs for the furnace. In the actual case the customer verified the possibility to reduce the carburizing temperature with about 15 ^{o}C without suffering in carburizing time..

The control concept may be possible to apply to furnaces where endogas is used. To function in that case it is probable that an extra inlet of nitrogen and water must be added to the diffusion zone.

5. CONCLUSION

The new atmosphere control system, in production since the beginning of 1997, has proven to yield a productivity increase of the order of 15%. The benefits of the system can also be utilised to lower the carburizing temperature. Quality improvement has been reached with regard to surface cleanliness.

REFERENCES

1. R Collin, S.Gunnarsson, D.Thulin, Journal of the Iron Steel Institute, (1972), p777