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HEAT TREATMENT IN AN ENVIRONMENTALLY-FRIENDLY GAS ATMOSPHERE[1]

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Abstract

The paper presents basic features of the application of active gas atmospheres in heat treatment furnaces. Disadvantages of these atmospheres are that they provide only partial protection of the steel surface and that they are not environmentally friendly as they spend the limited sources of natural gas and also emit environmentally harmful gas compounds, such as carbon dioxide CO_2 and nitrogen oxides NO_x. In order to enable the full protection of steel parts in heat treatment, a system for forming a protective gas atmosphere containing noble gas; argon or helium, has been developed. These two gases provide the absolute protection of the surface and have no harmful effects on the environment.

Key words: Active gas atmosphere; Noble gas atmosphere; Argon; Helium.

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1 INTRODUCTION

For the heat treatment of steel, different types of protective gas atmospheres are used. In most cases these are gas atmospheres obtained by the partial combustion of gaseous hydrocarbons (methane, propane, etc.) and oxygen from the air. Protective gas atmospheres are produced in separate gas generators, in gas generators installed beside the furnace retort and also by forming synthetic gas atmospheres in the furnace itself. Depending on the air-hydrocarbon ratio, gas atmospheres with different compositions of gaseous components, such as carbon monoxide CO, carbon dioxide CO_2, hydrogen H_2, water vapour H_2O and nitrogen N_2, are obtained.[1] In an appropriate ratio between the reducing and oxidizing gas components (CO/CO_2, H_2/H_2O), the surface of steel is protected from oxidation, which is the primary task of protective gas atmospheres. However, almost all gas components in these protective atmospheres can have other harmful effects on the surface of the treated steel part.

Table 1. Heat-treating atmosphere constituent gases[2]

Constituent gas	Symbol	Flammable	Toxic	Asphyxiant	Atmosphere function
Ammonia	NH_3	yes	yes	yes	Strongly nitriding
Argon	Ar	-	-	yes	Totally inert
Carbon dioxide	CO_2	-	yes (at high concentration)	yes	Oxidising and decarburising
Carbon monoxide	CO	yes	yes	yes	Carburising and middle reducing
Helium	He	-	-	yes	Totally inert
Hydrogen	H_2	yes	-	yes	Strongly reducing
Methanol	CH_3OH	yes	yes	yes	CO and H_2 generator
Natural gas	CH_4	yes	-	yes	Strongly carburising and deoxidising
Nitrogen	N_2	-	-	yes	Mostly inert

These components may take part in the reactions involving the interchange of carbon atoms on the steel surface, depending on the gas atmosphere composition, temperature and carbon activity.[3] These reactions can be described by equations for the thermodynamic equilibrium: $CO_2 + [C] \rightleftarrows 2CO$ and $H_2O + [C] \rightleftarrows H_2 + CO$.

The arrow pointing to the right marks the decarburization process, and that pointing to the left the carburization process. The decarburization and carburization processes have harmful effects on the surface layer of steel, changing its carbon content, and thus the properties of the surface layer of a steel part. Alloyed steels, particularly the steels alloyed with carbide forming elements, exhibit high affinity to carbon and also to oxygen and oxidizing gas components (CO_2 and H_2O). When these steels are heat treated, chrome oxides (in most cases Cr_2O_3) are often formed at a lower ratio of reductive gas components to oxidizing gas components (CO/CO_2 and H_2/H_2O) and chrome carbides (in most cases Cr_7C_3) at a higher ratio of reductive to oxidizing gas components. In addition to active gas components

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(CO, CO_2, H_2, H_2O), harmful effects are also caused by nitrogen (N_2) because it is absorbed in the surface layer of steel. At higher temperatures, nitrogen stabilizes austenite so that in the process of steel quenching, a higher content of austenite is retained in the hardened steel. Austenite is softer than martensite and it causes the occurrence of tensile stresses. As active gas atmospheres protect the steel surface only from oxidation, but not from other harmful changes in the chemical composition, they do not fully deserve to be called “protective”. The changes in the chemical composition in the surface layer of steel reduce the quality of the performed heat treatment. These negative effects of active gas atmospheres are mitigated when structural parts and tools are subjected to post-heat treatment mechanical processing by which the changed surface layer is removed. However, it does not apply to the parts, especially the tool parts, for which no post-heat treatment mechanical processing of the surface is planned. In that case, the above mentioned phenomena, such as decarburization, carburization, formation of chrome oxides or chrome carbides, and absorption of nitrogen, significantly reduce the quality of treated parts.

Active gas atmospheres contain gas components which are toxic (CO), combustible (CO, H_2) and explosive in contact with air. Therefore, the furnace gas installations must include elements ensuring a safe operation, which significantly increases the investment and operating costs.[4] Toxic and explosive gas atmospheres must not be released into the environment, but should be burnt using the oxygen from the environment air by means of a torch. In the burning process, carbon dioxide CO_2, water vapour H_2O and nitrogen oxides NO_x are formed and released into the atmosphere. The only desirable product of these gas atmospheres is the water vapour, while, on the other hand, the well known harmful effects of CO_2 and NO_x require special efforts in order to reduce their emission into the environment. Compared with power plants, furnaces for heat treatment emit significantly lower amounts of CO_2 and NO_x, but still there is a constant need to reduce these emissions wherever it is possible.

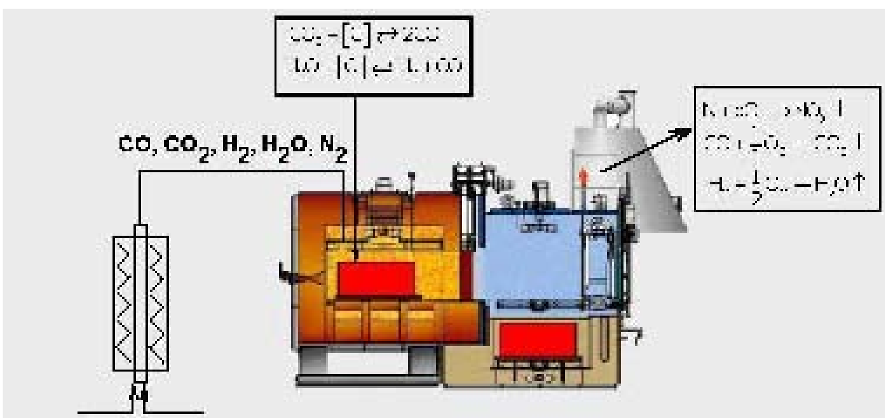

Figure 1. Principle of application of active gas atmospheres in heat treatment furnace.

2 EVELOPMENT OF FURNACES WITH ENVIRONMENTALLY-FRIENDLY GAS ATMOSPHERES

Conventional protective gas atmospheres provide the steel surface with only some degree of protection in the heat treatment process, while contributing to the depletion of the natural gas reserves and to the pollution of the environment and the Earth's atmosphere. Therefore, there is a need to develop a protective gas atmosphere system that would not allow the occurrence of harmful effects on the heat treated parts and that would be both ecologically acceptable and economically feasible. In industry, nitrogen (N_2) is used as an "inert" gas, but it is not completely inert to the heated steel since it is absorbed in the surface layer, changing the chemical composition and microstructure by increasing the content of soft, residual austenite in the hardened steel.

Only noble gases are completely chemically inert. In welding technologies, helium and argon are used as shielding gases. They are much more expensive than other gases used in engineering and their application in conventional gas atmosphere furnaces would not be economically feasible since the gas consumption during the process is very high. In order to enable reasonable consumption of costly argon or helium, a design with an economical system for forming the gas atmosphere had to be developed. The development of new designs and systems for forming the gas atmosphere was based on specific properties of argon and helium with respect to air, such as significant differences in the density of gases.[5] Argon is 40% heavier than air, and helium is seven times lighter than air. These facts are of importance for an efficient replacement of air atmosphere prior to the heating of charge, and consequently, the gravitational system was used to replace the air atmosphere with helium or argon.

In bell-type furnaces, helium is introduced from the top of the furnace, thus filling the retort and pushing out the air which is heavier than helium. When pit-type furnaces are concerned, argon is introduced close to the retort bottom. Argon then pushes the air out through the top of the retort and through an outlet valve which maintains the overpressure which prevents the air from coming into the retort. Chamber-type furnaces with horizontal retorts are not suitable for the application of either helium or argon because these furnaces do not enable the gravitational separation of the gas from the air at the point of the furnace opening.

The system for the formation of gas atmosphere in a furnace controls and monitors the introduction of a required amount of gas, which corresponds to the volume of the closed gas system in the furnace. Thus, a minimum amount of costly gas is expended. Therefore, these furnaces do not require a gas installation or a gas generator, but only a bottle of compressed gas of technical purity that would suffice for about 30 working cycles, depending on the furnace size.

3 APPLICATION OF THE DEVELOPED SYSTEM FOR THE FORMING OF NOBLE GAS ATMOSPHERE

On the basis of the system developed for the forming of noble gas atmosphere, appropriate designs of furnaces for the heat treatment of steel parts have been developed. A big advantage of protective noble gas atmospheres is that they prevent the harmful phenomena, such as decarburization, carburization, grain boundary oxidation and nitrogen absorption. The application of absolutely inert gases in the hardening and tempering of steel parts is particularly useful. Furnaces with noble gas atmospheres integrated with closed quenching basin have been developed for the hardening of steel parts and tools. Second type furnace was developed for heating in noble gas atmospheres and quenching in separate opened basins.

When hardening in a closed system is concerned, it is preferable to use a bell-type furnace with the helium gas atmosphere, below which there are a vestibule and a quenching basin.

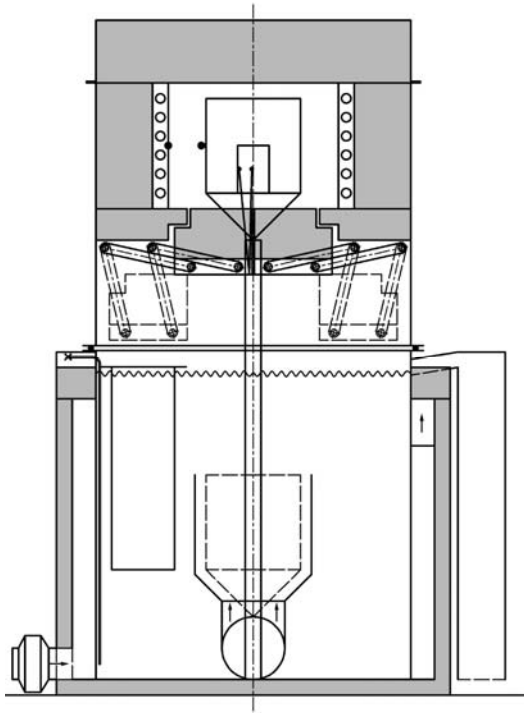

Figure 2. Bell-type furnace for helium atmosphere in a closed system with integrated quenching basen.

Helium is introduced into the upper part of the retort. It pushes the much heavier air downwards to the bottom of the vestibule and above the level of the quenching bath. As the charge is heated to the temperature of austenization, the retort doors open so that the lift can to transport the charge through the vestibule into the quenching bath. During the period of charge heating, the gas is expanding, and continues to do so in the vestibule as the charge passes to the quenching basin, so that the volume of gas is increased. Due to gravitation, the gas is stored in the external expansion vessel. This type of economic operation results in minimal consumption of costly helium as it is kept within the closed gas system of the retort and in the vestibule. After the cooling process in the quenching bath has been completed, the furnace with the vestibule is lifted into the upper position, and the lift elevates the hardened charge into the upper position for de-charging. Since the whole process of heating and transport the charge is carried out in the atmosphere of the noble gas helium, the surface of hardened parts remains completely unaffected from the surrounding atmosphere.

Another variant of the noble gas application is the case of quenching in separate open quenching basins (water, oil, salt bath, polymer solution). In that case, a pit-type furnace is used, and the noble gas is argon as it is heavier than air. Argon is introduced into the retort close to its bottom. The air is displaced to the top of the retort and passes through the outlet valve which maintains low overpressure in the retort. After austenization in the atmosphere of argon, parts are transported in the open air to the open quenching basins. The surface of parts is in contact with the surrounding air for a short time, which results in a light colouring of the surface. This can be easily eliminated by polishing.

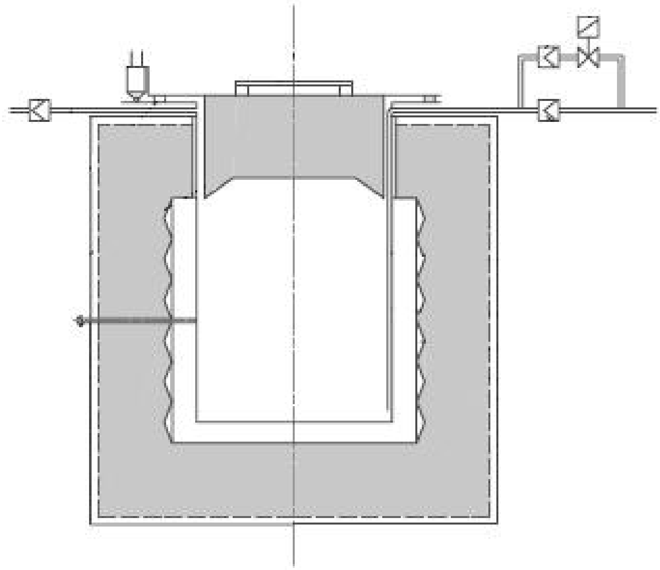

Figure 3. Principle of the application of argon in pit-type hardening furnaces for quenching in separate basins.

In addition to hardening furnaces, new designs of furnaces and systems for noble gas atmosphere formation for high-temperature tempering have been developed. Thus, the noble gas is used for both the heating process and the cooling process in the same system, in order to prevent the surface oxidation during the cooling phase of the process. Heating and cooling are carried out with a forced circulation of the noble gas in the retort. Due to specific differences in the density of the gases, the bell-type furnace is used for the tempering in helium and the pit-type furnace for the tempering in argon.

From the point of view of safety, furnaces with noble gas atmospheres are much simpler in their design than conventional furnaces with active gas atmospheres which contain combustible and explosive gas components.

4 CONCLUSIONS

Gas atmosphere furnaces, which are widely used in industry, have multiple harmful effects on the environment. On the one hand, non-renewable energy sources (natural gas) are used for production of gas atmospheres witch emit harmful gases; CO_2 and NO_x, in the atmosphere. In addition, these “protective” gas atmospheres provide the surface of heat treated steel constructive parts and tools with only partial protection, i.e. the protection from oxidation. Other phenomena (decarburization, carburization, grain boundary oxidation, nitrogen absorption) are not prevented, and it is these phenomena that have adverse effects on the surface of steel parts that are not subjected to post-hardening mechanical processing.

In contrast with active gas atmospheres, noble gases cannot cause any chemical changes on the surface of steel parts because they are absolutely inert. Another advantage of noble gases is that there are no harmful emissions related to their use.

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Argon and helium can be obtained from air, and after being used in furnaces for heat treatment, they are partially recovered and released into air without any effects on the environment.

The developed design of furnaces and the gas atmosphere system are based on the gravitational principle using a big difference in the density of gases, which enables a minimal consumption of costly gases, and consequently, an economic heat treatment of steel parts.

REFERENCES

1 Torsten Holm: Furnace Atmospheres, Linde gas special edition, Munich 2005.
2 P.F. Straton, M.S. Stanescu: An Introduction to Atmosphere Furnace Safety, Proceedings of the 22nd Heat Treating Society Conference, 2003, Indianapolis USA, 15-23.
3 B. Koroušič, M. Jenko, M. Stupnišek: Determining the gas composition that causes oxide scale formation during the decarburization of non-oriented electrical steel sheats. Steel Research 73(2002)2,63-68.
4 EN 746- Industrial Thermoprocessing Equipment Safety Requirements, CEN 1997.
5 M. Stupnišek, Ž. Kostanjski, R. Lisac: A new principle of equipment for the hardening of tools and dies, Proceedings of 7th International Tooling Conference, Torino 2006, Italy, Vol. I, 241-248.