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Furnace Gas Reactions with Steel

Each gas in a furnace atmosphere has a defined effect on the surface of the steel, and the effect depends on whether the steel carries carbon. The tables below set out what each constituent does to iron, steel, aluminium and copper, how carbon activity varies with carbon content and temperature, the gas mixture that holds a given carbon content in equilibrium, and the direction in which each element moves.

Reference only. This is a reference summary of published practice and it is not a specification of ours. The values are reproduced from the source tables, and what a particular furnace produces depends on the pumping system, the leak rate and the cycle. Final selection is confirmed on the job.

The individual gases and their effect on the metal

Metal	O2	CO2	CO	H2	CH4	H2O	N2
Iron	oxidising	oxidising	carburising	decarburising	carburising	oxidising	–
Steel	oxidising	oxidising, decarburising	carburising	decarburising	carburising	oxidising, decarburising	–
Aluminium	oxidising	oxidising	–	–	–	–	–
Copper	oxidising	oxidising	–	–	–	–	–
Iron oxide	–	–	reducing	reducing	reducing	–	–

Chemical effect of individual atmosphere constituents, reproduced from the source. A dash means no effect. Carbon dioxide and water vapour oxidise iron and also decarburise steel, which is why the steel row differs from the iron row. The last row is iron oxide rather than a metal, and it shows the three gases that reduce an already scaled surface.

Carbon activity in austenite

Carbon content, %	760 °C	800 °C	850 °C	900 °C	950 °C
0.05	–	–	0.03	0.03	0.02
0.1	–	–	0.06	0.06	0.05
0.2	–	0.15	0.13	0.13	0.11
0.4	–	0.33	0.27	0.27	0.21
0.8	1.0	0.90	0.61	0.61	0.51

Activity of carbon in austenite at various carbon contents and selected temperatures, relative to pure graphite. A dash means the source lists no value. The figure falls as the temperature rises at a fixed carbon content, and rises with the carbon content at a fixed temperature.

The gas mixture that holds a carbon content in equilibrium

Carbon content of steel, %	CO, %	CO2, %
0.05	70	30
0.8	95	5

Composition of carbon monoxide and carbon dioxide atmospheres in equilibrium with steels of two different carbon contents at 900 °C. The higher the temperature and the higher the carbon content of the steel, the greater the carbon monoxide content needed to hold the surface in equilibrium.

The three decarburising reactions

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Reaction	Running to the right	Running to the left
C + 2H2 = CH4	hydrogen removes carbon as methane	methane deposits carbon on the steel
C + CO2 = 2CO	carbon dioxide removes carbon as carbon monoxide	carbon monoxide deposits carbon on the steel
C + H2O = CO + H2	water vapour removes carbon as carbon monoxide	the reverse adds carbon

The three decarburising reactions, written with carbon on the left as in the source. Running to the right removes carbon from the steel, running to the left deposits it.

Which direction each element moves

Process	Element	Reacting gases	Direction of interchange
Oxidation	O2	H2	atmosphere to metal
Scale reduction		CO & CO2	atmosphere from metal
Bright annealing		–	no interchange
Carburisation	C	CO & CO2, CH4 & H2	atmosphere to metal
Decarburisation		CO & CO2, CH4 & H2	atmosphere from metal
Decarburisation-free annealing or hardening		CO & CO2, CH4 & H2	no interchange
Nitriding	N2	NH3 & H2	atmosphere to metal
Denitriding		NH3 & H2	atmosphere from metal
Nitrocarburisation	C + N2	CO & CO2, CH4 & H2, NH3 & H2	atmosphere to metal
Decarburisation or denitriding		CO & CO2, CH4 & H2, NH3 & H2	atmosphere from metal

Examples of heat treatment processes involving the interchange of elements, reproduced from the source. The direction is written out here where the source prints an arrow. The reacting gas shown against oxidation is reproduced as printed in the source.

What this means for a tool steel cycle

Aobo Steel, tool steel supplier

Aobo Steel supplies tool steel to distributors and mold, tool and die shops, including D2, D3, DC53, A2, O1, H13, H11, H10, H21, S7, M2, M42, L6, P20 and 420 and 440C stainless. Forged or hot rolled, annealed or pre-hardened, cut to your sizes, with test certificates.
Source, Controlled Atmospheres for Heat Treatment, R. Nemenyi and G. H. J. Bennett, Pergamon Press, 1984.

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