Furnace atmospheres 1

Gas Carburizing and Carbonitriding

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AGA

Contents

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Introduction

The composition, function and control of the furnace atmosphere are of crucial importance for the results in all hardening operations. The purpose of this booklet is to provide a brief introduction to the properties and function of the protective gas in carburizing and carbonitriding. The special characteristics of nitrogen-based atmospheres are also described here.

The booklet comprises the first part of a planned series that will deal with:

- Gas carburizing and carbonitriding
- Neutral hardening and neutral annealing
- Nitriding processes
- Sintering
- Brazing

The series will be produced in both a Swedish and an English version.

Why steels are hardened

The machinability and hardness of steels vary with their carbon content. The highest hardness in a hardened steel is obtained when the carbon content of the steel is high, up around 1% C (figure 1). A steel with such a high carbon content is hard, but unfortunately it is also brittle. Such steels can therefore not be used in machine parts, such as gears, that are exposed in operation to bending and tensile stresses. A carbon content as high as 1% C in the steel also makes it difficult to perform metal cutting operations such as turning. On the other hand, case-hardening steels and steels for carbonitriding have a low carbon content, which means they possess good machinability.

Gas carburizing (and carbonitriding) is a case-hardening treatment where a finished part is exposed to a carburizing atmosphere at a high temperature. This treatment creates a surface layer (case) with an elevated carbon content. The case is typically 0.1–1.5 mm (0.004-0.060 inches) thick. After carburizing, the part is cooled rapidly, which causes hardening (figure 2). As a result, the case is hardened to a hardness corresponding to its carbon content, as shown in figure 1. The gas-carbu-rized (carbonitrided) part can be said to comprise a kind of composite material, where the carburized surface is hard but the unaffected core is tough. This gives the part a very fine combination of properties with high strength, wear resistance and toughness, see figure 3.

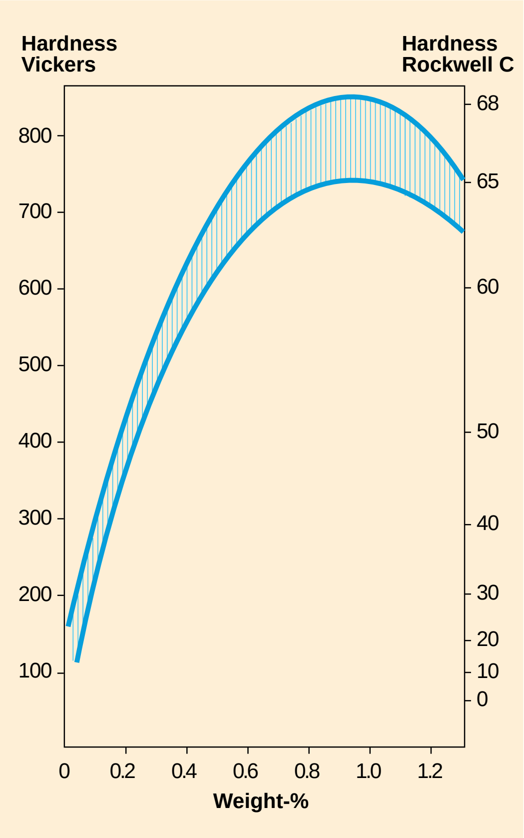

Figure 1. Hardness as a function of carbon content in hardened steel. The hatched area shows the effect of retained austenite and alloy content of steel.

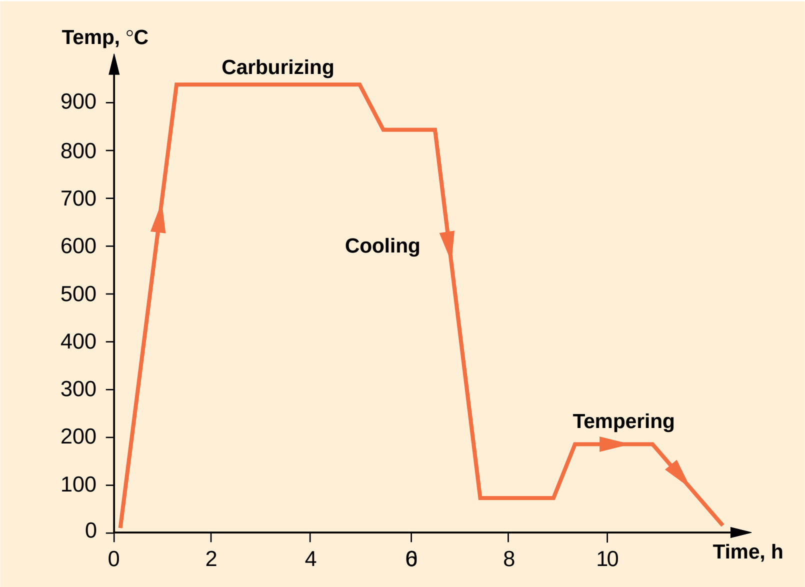

Figure 2. Gas carburizing

In order for a hard case to form after cooling, a martensitic structure must form. The hardenability of the steel must therefore be sufficiently good. Hardenability is dependent on the alloying content of the steel, and increases with an increasing concentration of alloying elements. Gas-carburizing steels must therefore contain a certain amount of alloying elements. Examples of some gas-carburizing steels are given in table 1.

Table 1. Composition of steel types that can be carburized and hardened

Standards			%C	% Mn	% Cr	% Ni	% Mo
Sweden	Euronorm	USA					
21 27	16MnCr5	-	0.13 – 0.19	1.00 – 1.30	0.8 – 1.10	–	–
25 06	20NiCrMo2	8620	0.17 – 0.23	0.60 – 0.95	0.35 – 0.65	0.35 – 0.75	0.15 – 0.25
25 11	-	-	0.13 – 0.18	0.70 – 1.10	0.60 – 1.00	0.80 – 1.20	max 0.10
25 12	-	4320	0.18 – 0.23	0.70 – 1.10	0.60 – 1.00	0.80 – 1.20	max 0.10
25 23	17NiCrMo5	4317	0.17 – 0.23	0.70 – 1.10	0.80 – 1.20	1.00 – 1.40	0.08 – 0.16

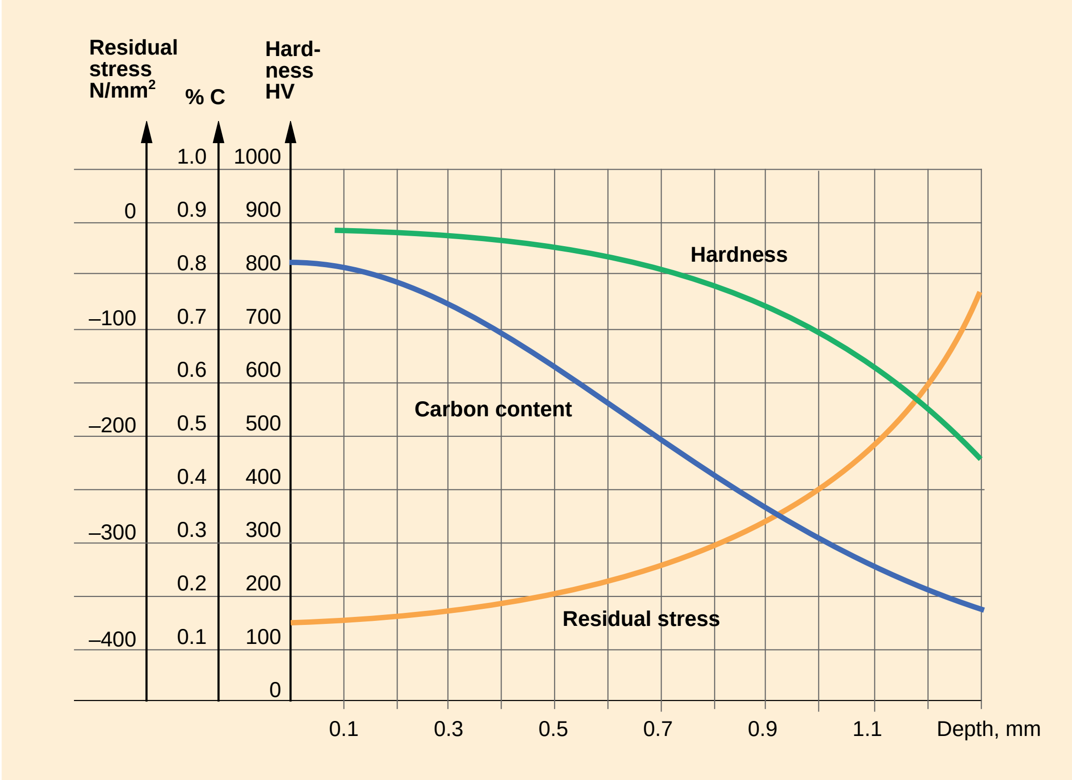

Figure 3. Hardness, carbon content and residual stress gradients

Carbonitriding is often applied for steels that have a lower alloying content than the gas-carburizing steels. In the carbonitriding process, carbon is added to the surface in the same manner as in case hardening, but in addition nitrogen is supplied by the addition of ammonia to the atmosphere. Typical surface nitrogen contents obtained lie in the range 0.1–0.4 weight-% N. The nitrogen increases hardenability and compensates for the lower alloying content of the steel. It is therefore possible to surface-harden low-alloy and carbon steels by means of carbonitriding.

Gas carburizing and carbonitriding are done on highly stressed machine parts. Examples are transmission parts, car engine parts, roller and ball bearings, rock drill parts, wear parts, fatigue-stressed parts such as shafts etc.

Table 2. Composition of steel types that can be carbonitrided

Steel type	% C	% Si	% Mn	% P	% S	% Pb
Steel for cold-rolled strip	0.07	max 0.30	0.25 - 0.45	max 0.030	max 0.040	-
Free-cutting steels	max 0.14	max 0.05	0.90 - 1.30	max 0.11	0.24 - 0.35	0.15 - 0.35
	max 0.14	max 0.05	0.90 - 1.30	max 0.11	0.24 - 0.35	0.15 - 0.35
	0.12 - 0.18	0.18 - 0.40	0.80 - 1.20	max 0.06	0.15 - 0.25	-
	0.12 - 0.18	0.10 - 0.40	0.80 - 1.20	max 0.06	0.15 - 0.25	0.15 - 0.35
General constructional steel	max 0.20	max 0.5	(1.0- 1.6)	max 0.05	max 0.05	-

How steels are hardened

When machining of the parts is completed, they are placed in a bas-ket or mounted (hung) on some type of fixture. The basket (fixture) is charged into a furnace, which normally has a temperature of 800 – 850 °C (1472 – 1562 °F) for carbonitriding and about 900 – 950 °C (1652 – 1742 °F) for gas carburizing.

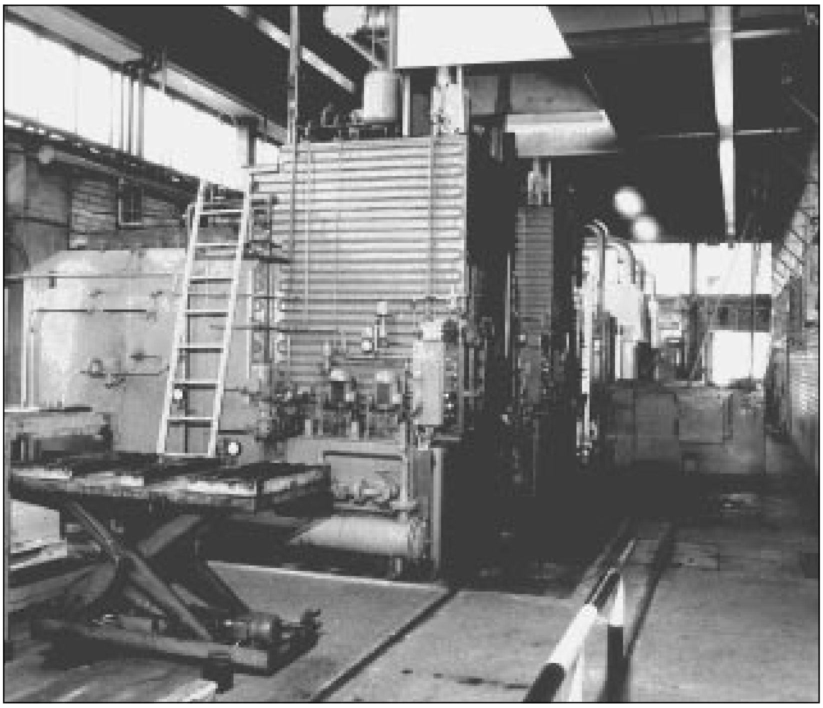

Figure 4. Example of furnace and charging (above). The parts are loaded in baskets or on fixtures (at right) before they are taken to and loaded into the furnace by means of a car.

Conveyor-belt furnaces, shaker-hearth furnaces or rotary-retort fur-naces are used for small parts, such as screws. The furnaces that are used vary widely in size and appearance. Within the automotive indus-try, which uses mass production lines, pusher-type furnaces are very common. Within the metalworking industry, the sealed quench furnace is common. The furnace has a wide range of applications. Cylindrical retort furnaces are common when long parts are to be gas carburized.

There is a carburizing gas atmosphere in the furnace. When the charge has reached the carburizing temperature, the effective trans-fer of carbon from gas to steel surface begins. Carburizing is allowed to proceed until the desired depth of penetration is reached. The charge is then moved from the furnace chamber to a cooling chamber, which normally has an oil tank. The charge is lowered into the oil tank. After cooling, the charge normally undergoes washing and tempering. Dimension-adjusting grinding is normally required before the parts are completely finished.

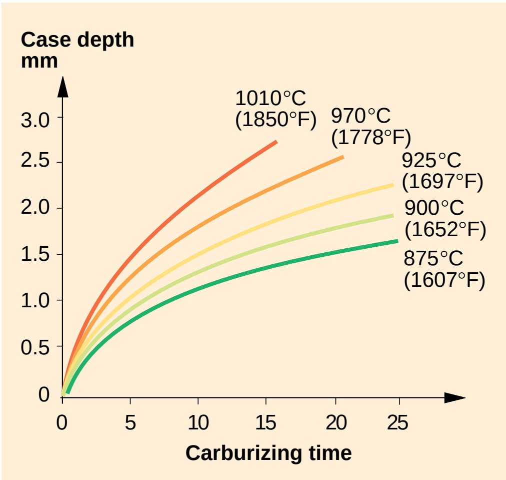

Figure 5. Approximate relationship between temperature, time and carburizing depth.

Interaction between furnace atmosphere and steel

Function of the furnace atmosphere

The primary function of the furnace atmosphere is to supply the needed carbon and provide the right surface carbon content (surface nitrogen content) in carburized (or carbonitrided) parts. The atmosphere must have a composition that corresponds to these needs and that can eliminate (buffer) the disturbances caused when air enters the furnace via an open door or leakage. To control the surface carbon content, it must be possible to control the composition of the gas. This is normally done with a separate enriching gas, a hydrocarbon, usually propane or methane.

In order to achieve an even heat treatment result, both temperature and gas composition must be equal throughout the volume of the charge. This is achieved by forced gas circulation by means of a fan. For the sake of safety, the supplied gas flow should create a certain positive pressure in the furnace in order to prevent air from entering.

Another safety aspect is that it must be possible to purge a combustible gas from the furnace in the event of, for example, too low fur-nace temperature, power failure and low furnace pressure.

The functions of the furnace atmosphere are thus to:

- supply the necessary carbon (and nitrogen)
- provide the right carbon (and nitrogen) content
- buffer
- purge
- give uniform results
- maintain a positive pressure
- permit safety purging

The carburizing process

The transfer of carbon from the gas to the steel surface takes place via the reaction illustrated in figure 6.

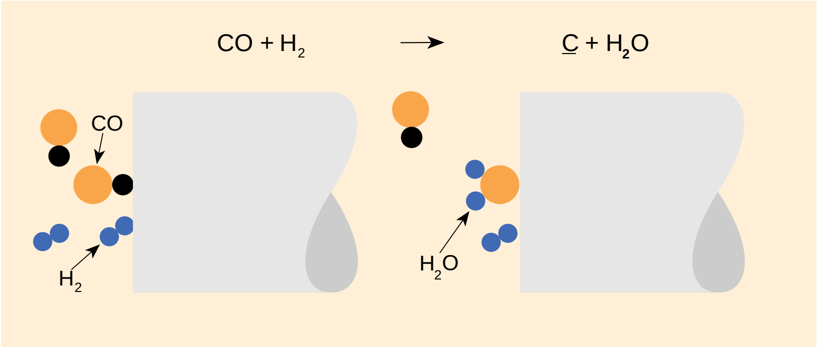

Figure 6. Schematic illustration of carburizing process

In the above reaction, carbon monoxide (CO) and hydrogen (H_2) react so that carbon (C) is deposited on the surface and water vapour (H_2O) is formed. A requirement is therefore that the furnace atmosphere must contain so much carbon monoxide and hydrogen that the carburizing process can proceed in a uniform and reproducable fashion. According to the fundamental principles of chemistry, the equilibrium conditions for the carburizing reaction are described by an equilibrium constant expressed by:

$$K_1 = \frac{a_c \cdot P_{H_2O}}{P_{CO} \cdot P_{H_2}}$$

where PH_2O etc. is the partial pressure , which is obtained at atmospheric pressure from the vol-% value divided by 100. The value of K is dependent on the temperature and can easily be calculated from the relationship:

$$\log K_1 = -7{,}494 + \frac{7130}{T}$$

where T is the absolute temperature in Kelvin.

a_c is termed carbon activity and is a measure of the “carbon content” of the gas. We see that a_c can be calculated when K and the gas composition are known.

When the carbon activity of the gas, a_c^g, is greater than that of the steel surface, a_c^s , there is a driving force to transfer carbon as expressed by the following equation:

$$\frac{dm}{dt} = k \cdot (a_c^g - a_c^s) \text{ or } \frac{dm}{dt} = k^1 \cdot (c_c^g - c_c^s)$$

where m designates mass, c concentration per unit volyme and t time, i.e.

$\frac{dm}{dt}$ expresses a carbon flow in units of $kg/cm^2 \cdot s$ or $mol/m^2 \cdot s$,

k or k^1 is a reaction rate constant dependent on temperature and gas composition in accordance with figure 8. For cracked methanol, $k^1 \approx 2 \cdot 10^{-7}$ m/s and for endothermic gas $k^1 \approx 1.2 \cdot 10^{-7}$ m/s.

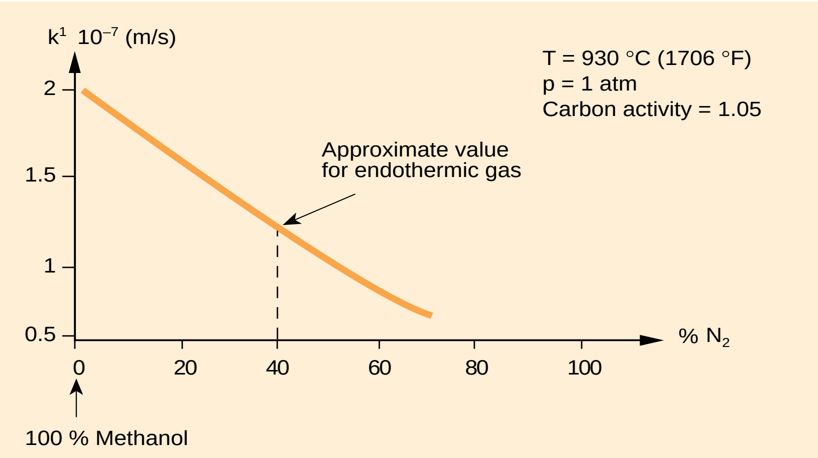

Figure 7. Carbon transfer rate coefficient as a function of the mixing ratio N_2/methanol

From the expression for carbon transfer, it is evident that there are two fundamentally different ways to increase carbon transfer. In the first place, the difference $a_c^g - a_c^s$ can be made as large as possible. This means maximizing a_c^g. The upper limit is given by $a_c^g = 1$, which is the limit for formation of free carbon, soot. Another upper limit is given by the fact that the carbon activity may not exceed the value that corresponds to carbide formation in the steel. This principle is used in what is called “boost carburizing” or two-stage carburizing.

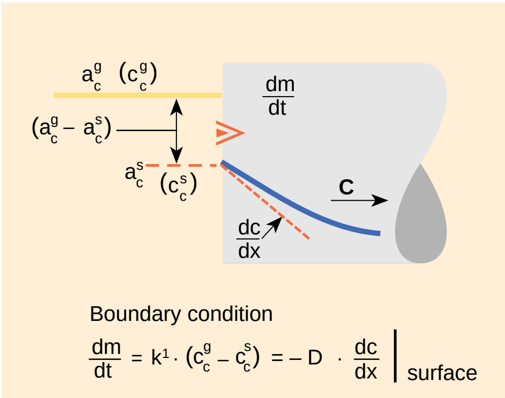

Figure 8. Carbon flows and activities in the gas/steel interface

In the second place, the reaction rate constant k can be maximized. With some simplification, it can be said that k reaches its highest value when the product $P_{CO} \cdot PH_2$ is greatest, i.e. for an atmosphere with equal parts carbon monoxide and hydrogen.

The carbon mass transfer from gas to surface must be equal to the mass transfer further into the steel. Fick's 1st law gives an expression for the flow of carbon in the steel as a function of the carbon concentration degree dc/dx:

$$\frac{dm}{dt} = -D \cdot \frac{dc}{dx}$$

D here is a temperature-dependent diffusion coefficient for carbon (and nitrogen), see table 3.

	D_o, m²/s	Q, kJ/mol	D(900°C)m²/s
Carbon	11 10^{-6}	129	20 10^{-12}
Nitrogen	20 10^{-6}	145	7 10^{-12}

Table 3. Typical values of the diffusion coefficient for carbon and nitrogen in austenite expressed as
$D = D_o \cdot \exp - Q/RT$ (R = 8.314 J/mol · K) *with* D {900°C (1652 °F)} *as an example.*

Since mass balance must exist, the following boundary condition applies at the steel surface:

$$k \cdot (a_c^g - a_c^s) = -D \cdot \frac{dc}{dx}$$

The difference $a_c^g - a_c^s$ is great at the beginning of the carburizing process and later declines, since a_c^s, the surface carbon content, increases.

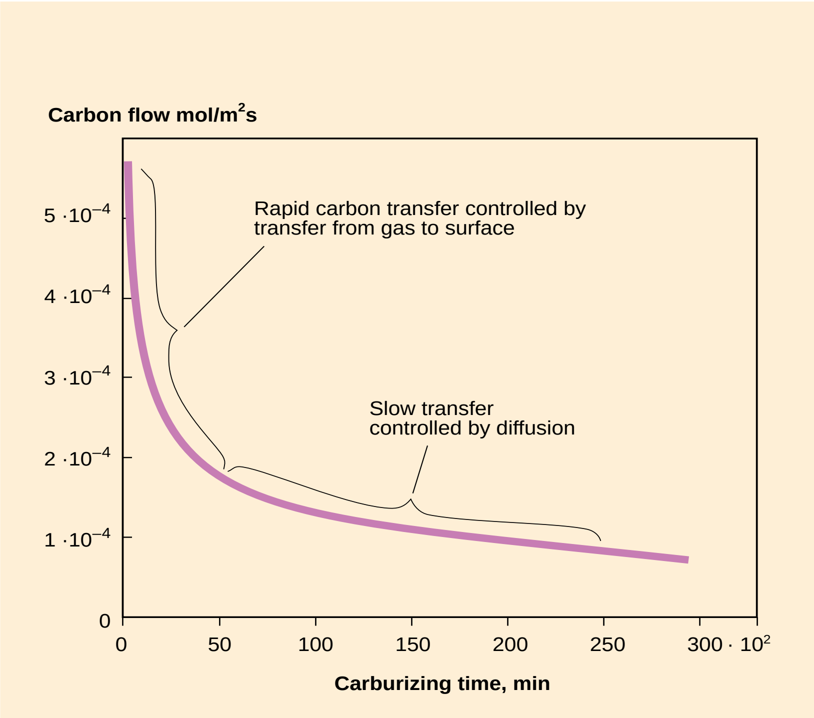

Figure 9. Variation of carbon flow

The following rate-limiting steps therefore exist for carbon transfer in different phases of a carburizing cycle:

– Transfer from gas to surface is the limiting factor in the beginning

– Diffusion in steel becomes rate-limiting during the latter part of the carburizing cycle.

Gas composition and gas flow can be adjusted to obtain the best economy and fastest carburization. During the phase when the transfer of carbon from gas to surface is rate-determining, the carbon activity of the gas shall be as high as possible, at the same time as the product $PC_O \cdot PH_2$ shall be maximized.

Relationship between carbon activity and dew point, CO_2 and O_2 analysis

According to the preceding paragraph, the carbon activity of the furnace atmosphere can be calculated from:

$$a_c = \frac{K_1 \cdot P_{CO} \cdot P_{H_2}}{P_{H_2O}}$$

The equation is valid under conditions of equilibrium, i.e. in the state (the gas composition) the system would assume if it were left undisturbed for an infinite length of time. Practical experience shows that the assumption of equilibrium in the gas phase is reasonable.It is therefore possible to control the gas composition to the desired carbon activity if the value of the equilibrium constant K is known. From the expression above, we see that the carbon activity can be controlled if P_{CO}, P_{H_2} and P_{H_2O} can be controlled. This is the background of dew point control (a certain value of P_{H_2O} corresponds to a certain dew point), where P_{CO} and P_{H_2} are known and P_{H_2O} is controlled to obtain the desired a_c.

Since we have assumed that equilibrium exists in the gas, equilibrium also exists for the carbon-transferring reactions:

$$2CO \leftrightarrows \underline{C} + CO_2 \; ; \quad K_2 = \frac{a_C \cdot P_{CO_2}}{P_{CO}^2}$$

$$CO \leftrightarrows \underline{C} + {}^1/_2\, O_2 \; ; \quad K_3 = \frac{a_C \cdot P_{O_2}^{1/2}}{P_{CO}}$$

We can therefore express the carbon activities in the furnace gas in the following alternative ways:

$$a_c = K_2 \cdot \frac{P_{CO}^2}{P_{CO_2}}$$

$$a_c = K_3 \cdot \frac{P_{CO}}{P_{O_2}^{1/2}}$$

It is evident from this that the carbon activity of the gas can be controlled by controlling the CO_2 content or the O_2 content, provided that P_{CO} is known. CO_2 control with an IR instrument and O_2 control with an oxygen probe are practical ways to do this. See further the tables 4-6. The concept “carbon potential” is explained on the next page.

Table 4: Relationship between carbon potential, temperature and dew point in some nitrogen/methanol atmospheres. ***See Appendix 1.***

Table 5: Relationship between carbon potential, temperature and CO_2 content in some nitrogen/methanol atmospheres. ***See Appendix 2.***

Table 6: Relationship between carbon potential, temperature and oxygen content determined as an output signal in millivolts from an oxygen probe in some nitrogen/methanol atmospheres. ***See Appendix 3.***

Carbon potential

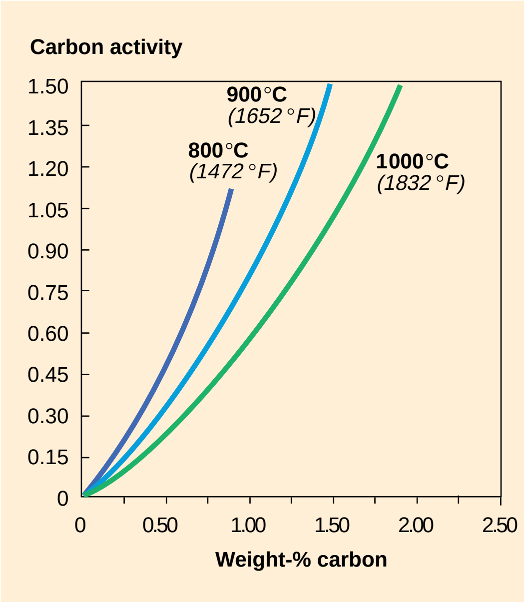

Figure 10. Relationship between carbon activity and carbon content in pure iron for some different temperatures

In practice, the concept “carbon potential” is usually used instead of carbon activity. The carbon potential of a furnace atmosphere is equal to the carbon content that pure iron would have in equilibrium with the gas. The relationship between carbon activity a_c and carbon potential c_p is expressed by:

$$a_c = \gamma^{\circ} \cdot \frac{x_C}{1 - 2x_C}$$

where

$$x_c = \frac{C_P / 12{,}01}{C_P / 12{,}01 + (100 - CP) / 55{,}85}$$

and

$$\gamma^{\circ} = \exp \{ [5115{,}9 + 8339{,}9\, x_c / (1 - x_c)] / T - 1{,}9096 \}$$

γ° is the activity coefficient and X_c is the carbon content expressed as a mole fraction.

A simpler expression of the formula is usually used to calculate the relationship between carbon content in low-alloy case-hardening steels, C, and carbon potential, C_p.

$$\log \frac{C_P}{C} = 0{,}055 \cdot (\%Si) - 0{,}013 \cdot (\%Mn) - 0{,}040 \cdot (\%Cr) + 0{,}014 \cdot (\%Ni) - 0{,}013 \cdot (\%Mo).$$

Nitrogen activity

In carbonitriding, not only carbon activity but also nitrogen activity is an important parameter. There is, however, no reliable method available today for controlling the nitrogen activity of the gas atmosphere directly. Instead, empirical results are used as regards the relationship between the ammonia content of the gas supplied to the furnace, the residual ammonia content and the measured nitrogen content of the steel. In principle, the nitrogen activity is expressed by the equilibrium:

$$NH_3 \rightarrow \underline{N} + {}^{3}/_{2}\, H_2$$

with

$$K_4 = \frac{a_N \cdot P_{H_2}^{3/2}}{P_{NH_3}}$$

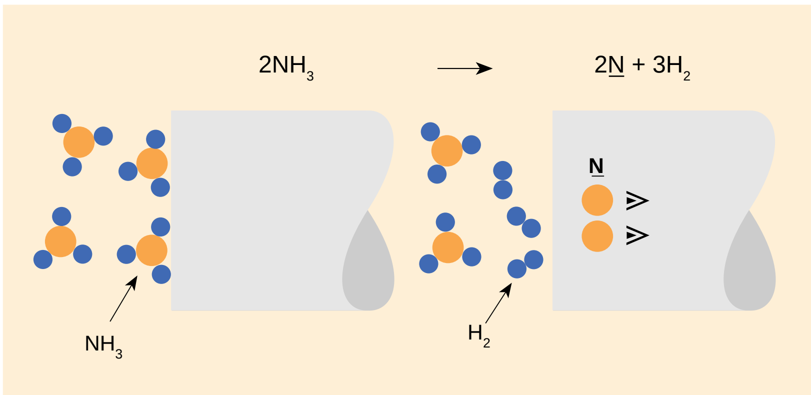

Figure 11. Schematic illustration of nitriding process

Most of the supplied ammonia decomposes into hydrogen and nitrogen in accordance with the equation $2\ NH_3 \rightarrow N_2 + 3H_2$. The portion that does not decompose is called residual ammonia and is the active component for nitriding. Theoretically, it is therefore possible to control the nitrogen activity by analyzing the NH_3 and H_2 content of the furnace gas.

Carbon profile

Depending on how the carbon activity of the gas, a_c^g, and the carbon transfer rate of the gas, k, are allowed to vary during the carburization cycle, different forms of the carbon concentration profile can be achieved. Two cases with the same carburizing time and temperature but with different curve forms are shown in the figure below. Which curve form is chosen depends on what balance of properties and productivity is desired.

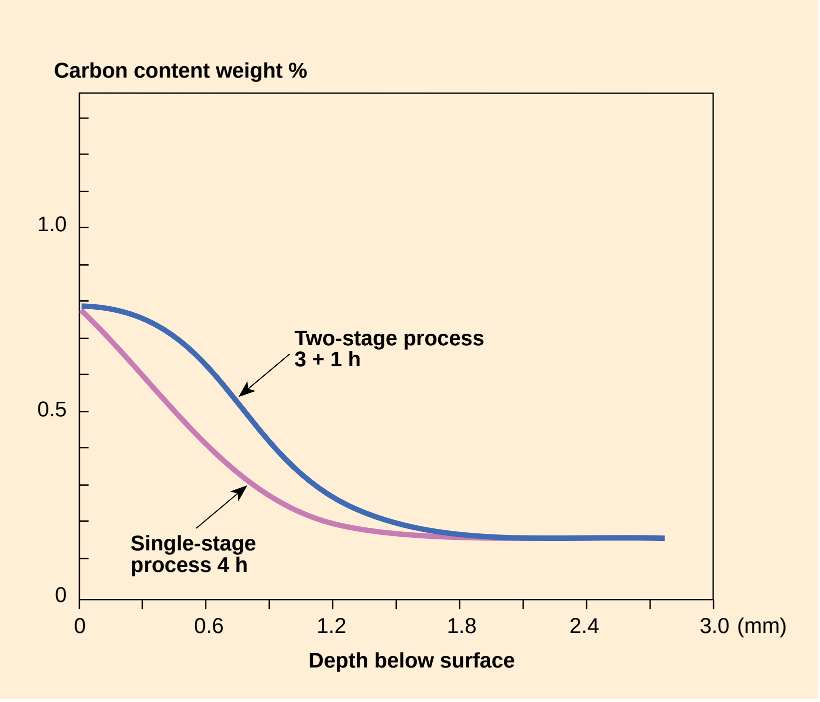

Figure 12. Calculated carbon concentration profiles for two carburizing processes with an identical total carburizing time, 4 hours, and carburizing temperature, 930°C (1704 °F), but with different carbon potentials of the gas.

– "Single-stage process" = constant carbon potential

– "Two-stage process" = high carbon potential for the first three hours and low carbon potential for the last hour.

AGA's concept

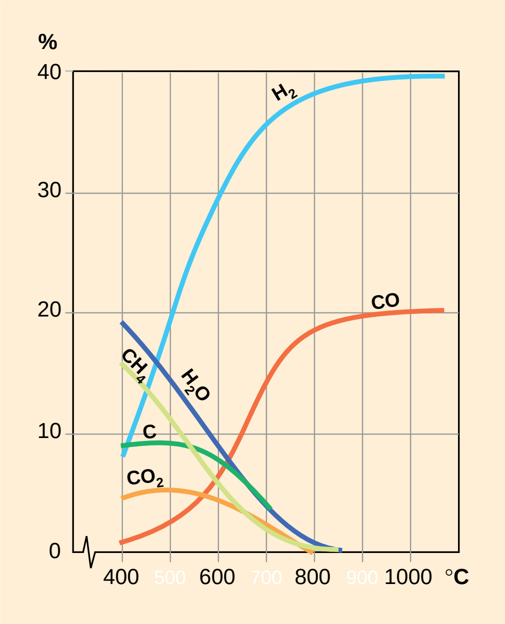

Figure 13. Cracking of a 40% nitrogen/60% methanol mixture.

According to the foregoing, the carburizing atmosphere should contain carbon monoxide (CO), hydrogen (H_2) and nitrogen (N_2). It was previously common practice to achieve a suitable atmosphere by means of incomplete combustion of propane or methane with air in accordance with the reactions:

$$C_3H_8 + 7{,}2 \text{ air} \rightarrow 5{,}7\ N_2 + 3\ CO + 4\ H_2$$

$$CH_4 + 2{,}4 \text{ air} \rightarrow 1{,}9\ N_2 + CO + 2\ H_2$$

Mixing and combustion of fuel and air takes place in special endothermic gas generators.

AGA's solution involves creating the furnace atmosphere directly in the furnace chamber by supplying nitrogen and methanol. The methanol cracks on entering the furnace to form carbon monoxide and hydrogen in accordance with the following reaction:

$$CH_3OH \rightarrow CO + 2H_2$$

For every litre of methanol that is added, approximately 1.7 m^3 of gas consisting of one part CO and two parts H_2 is formed. Different gas compositions are obtained by varying the mixing ratio between nitrogen and methanol. Compared with endothermic gas, the nitrogen/methanol system offers two essential advantages: The gas flow and the gas composition can be adjusted to the particular need existing at any time.

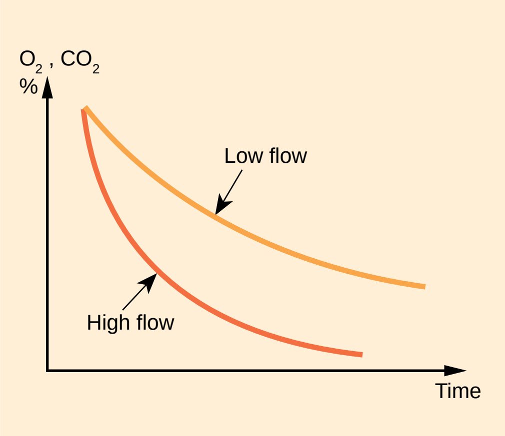

Figure 14. Purging of furnace with inert gas.

A high gas flow is desirable in the following cases:

- At the beginning of a cycle when the furnace is originally air-filled or has been contaminated with air after a door opening. The higher the gas flow is, the faster the right gas composition will be obtained.
- When the carbon demand is great, i.e. at the beginning of a process or in cases with a large charge surface area.

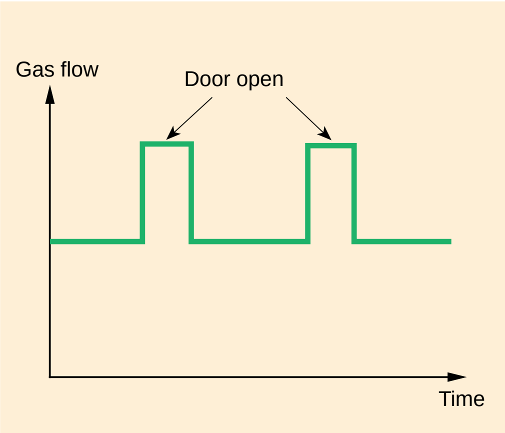

Figure 15. The gas flow can be adjusted to the demand.

Low gas flow can be used in the following cases:

- When the furnace is empty.
- When the carbon demand is low, i.e. at the end of a process or in cases with a small charge surface area.

The need to vary the gas composition parallels to some extent the need to vary flow. A high proportion of methanol, i.e. active portion CO + H_2, is required in the beginning of a cycle when the carbon demand is great. High nitrogen content can be used when the fur-nace is empty during purging and when the carbon demand is low.

The advantages of the nitrogen/methanol system are thus based on the fact that the gas flow and the gas composition can be varied. In order for this advantage to be exploited to the full, a more advanced flow control system is required than is customary for endothermic gas. Continuous flow control with mass flow meters and motorized valves is the most advanced type of system. Fixed flow combined with solenoid valves is another possibility. Even being able to adjust the gas flows manually is a considerable advantage.

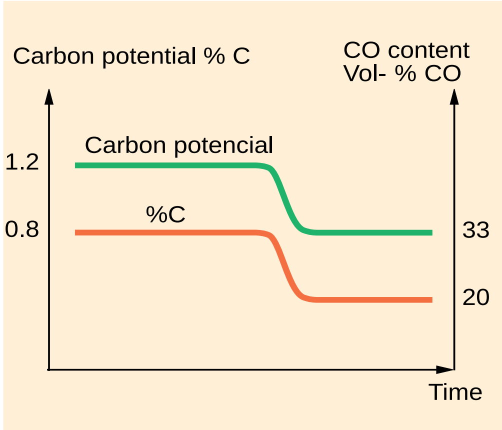

Figure 16. Example of how the gas composition can be varied by changing the N_2 / methanol ratio during a carburizing cycle.

Description of a nitrogen-based gas system

A nitrogen-based gas system for heat treatment can be divided into four parts:

– media storage
– distribution to furnaces
– control and regulation
– intake into furnace

Media storage

The carrier gas for gas carburizing is generated from nitrogen and methanol. The enriching gas is a hydrocarbon, propane or methane, possibly together with air, that is used to control the carbon potential. For carbonitriding, ammonia is also required.

The nitrogen is stored by small consumers in compressed gas cylinders and by large consumers in liquefied form in a vacuum-insulated tank. The best alternative for any given case is dependent on a number of factors, but tank storage is the most common among heat-treatment companies.

Methanol is stored in tanks of varying size depending on the rate of consumption. Small consumers fill their tanks from barrels, while large consumers fill them from road tankers.

Roughly the same rule applies for propane and ammonia, i.e. that small consumers use cylinders or cylinder bundles and large consumers use tanks. Propane and ammonia differ, however, from the other media in that they liquefy at relatively low pressures. These "gases" are therefore normally stored in liquid form.

Distribution to furnace

The nitrogen leaves the storage tank at a medium pressure set on the tank or cylinders. Inside the industrial premises, the pressure is reduced before the gas reaches the furnaces.

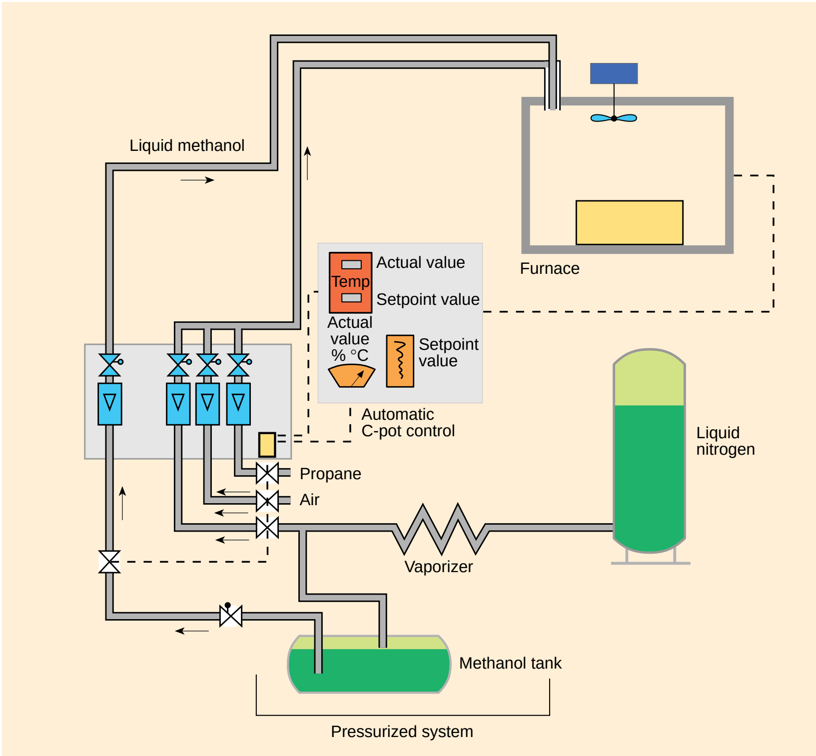

Figure 17. Nitrogen-based gas system

Methanol is charged into the piping system by means of pressurized nitrogen gas or a pump. If pressurized nitrogen is used, the methanol passes through one or more degassing devices that remove dissolved nitrogen gas on the way to the furnaces.

Propane and ammonia are transported by the pressure in the storage vessels.

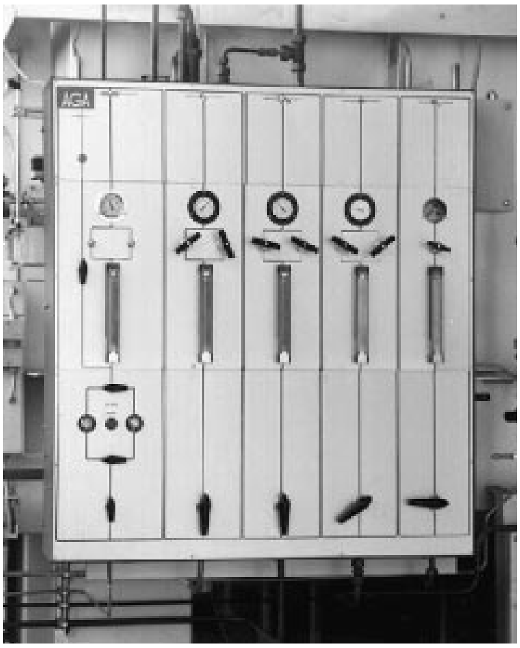

Figure 18. Flow control panel

Control and regulation

At the furnaces there are flow panels, figure 18, where the flow for each medium is adjusted and read. There the gases are mixed while the liquid methanol continues in a separate pipe.

During operation a carrier gas is produced from suitable proportions of nitrogen and methanol. Propane, air and ammonia are normally added as needed via a control system.

As a safety precaution, all media except nitrogen should have safety shut-off devices. The most common method is that all additions can only be made above a given temperature. The additions should also be stopped at a given minimum flow or nitrogen pressure. Generally, the inert properties of the nitrogen should be used for protection wherever possible.

Intake into furnace

The gaseous components in nitrogen-based systems are introduced in the same way as gas from other systems, i.e. so that optimum mixing and circulation are obtained.

For methanol, which is introduced in liquid form, however, a special technique is required. AGA has developed different lances for this so that good cracking and mixture are obtained regardless of type of furnace, location of intake, whether a fan is used etc (Figure 19).

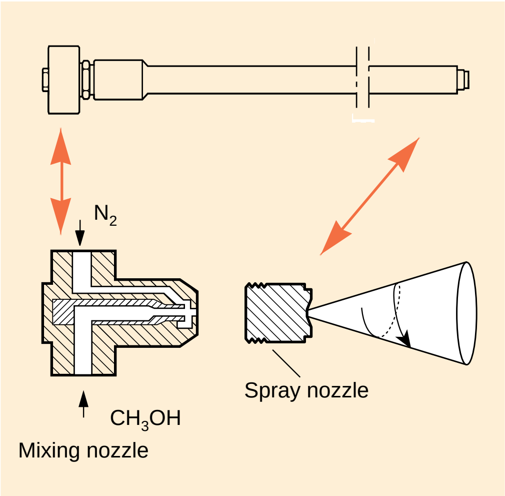

Figure 19. Example of injection lance

Results

When the results achieved with nitrogen-based systems are evaluted, four factors in particular stand out:

- production
- reproducibility
- safety
- economy

Production

The nitrogen gas technique often paves the way to higher production in existing plants.

The simplicity of the system in itself reduces production disruptions. Its flexibility - in that each medium is controlled separately - permits variations during the course of the process, especially during carburization, so that a shorter process time is achieved. Moreover, it can be shown that of all the carrier gases existing today, nitrogen/methanol mixture provides the fastest carbon transfer from gas to steel. In the case shown in figure 20 below, the carburization depth has been increased by 0.15 mm (0.0059 inch), equivalent to about 15%. Translated into a time saving, this would be equivalent to 30–45 minutes.

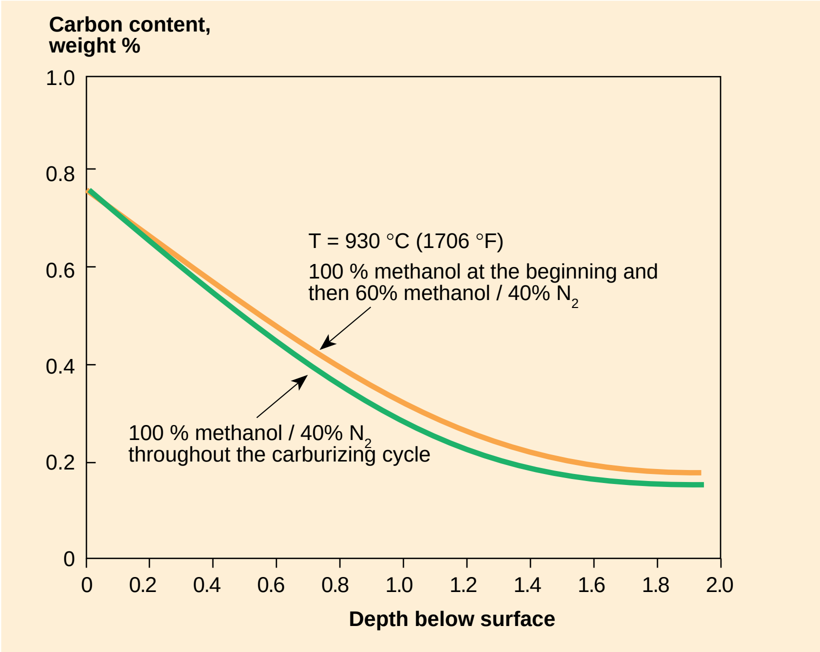

Fig. 20. Two carbon concentration profiles from carburization showing that a greater carburization depth is achieved if 100% methanol is used at the beginning of the carburizing cycle.

Nitrogen also makes it possible to prevent the charge from being ruined in connection with power failures and the like.

Reproducibility

The simplicity of the system also permits a uniform composition of the atmosphere in a furnace to be achieved. Uniformity in turn means fewer rejections and makes it possible to work with closer tolerances on surface carbon content, hardness and case depth.

Safety

Because nitrogen/methanol mixture does not form a combustible and toxic gas until the furnace chamber, many of the traditional risks of similar systems are eliminated.

Because of the inert properties of nitrogen, using nitrogen gas as a base in the gas system also enables many other risks to be reduced, such as explosions in connection with rapid temperature drops, oil fires etc.

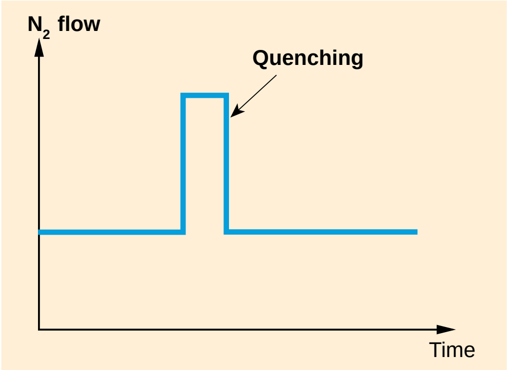

Figure 21. Temporary increase of nitrogen flow at the moment of quenching to counteract negative pressure, which could draw air into the furnace.

Economy

All of the factors mentioned above contribute towards good overall economy. In evaluating the influence of the gas system on the economy of the process, two factors in particular can be pointed out:

- For nitrogen-based gas systems, the fixed cost is a small percentage of the total cost. Due to the low investment required, low maintenance costs, low material costs and low electricity costs etc, the quantity of gas consumed is the dominant cost. This in turn means that it really pays to adjust consumption to the actual need. Reducing the gas flow by up to 30% has proved to be possible. Moreover, less gas is consumed at the start, and very small flows can be used when the furnace is empty. In this way, the total gas saving can be even higher, in some cases up to 50%.

- With nitrogen-based systems, the productivity of the process can often be enhanced in a number of ways. In the first place, its higher operational reliability permits high capacity utilization. In the second place, the quality of the gas ensures uniform and high yields. In the third place, the composition of the gas can be controlled to minimize the process time. In the fourth place, both labour and production time can be saved due to the fact that the start-up time after weekend interruptions or production stoppages is reduced.

The size of the savings that stand to be made varies between different furnaces and processes.

Appendices

Appendix 1

Table 4a: Dew point (°C) for different carbon potentials in an atmosphere consisting of 100% cracked methanol and 0% nitrogen.

Table 4b: Dew point (°C) for different carbon potentials in an atmosphere consisting of 60% cracked methanol and 40% nitrogen.

Table 4c: Dew point (°C) for different carbon potentials in an atmosphere consisting of 20% cracked methanol and 80% nitrogen.

Appendix 2

Table 5a: CO_2 content (vol-%) for different carbon potentials in an atmosphere consisting of 100% cracked methanol and 0% nitrogen.

Table 5b: CO_2 content (vol-%) for different carbon potentials in an atmosphere consisting of 60% cracked methanol and 40% nitrogen.

Table 5c: CO_2 content (vol-%) for different carbon potentials in an atmosphere consisting of 20% cracked methanol and 80% nitrogen.

Appendix 3

Table 6a: Output signal from an oxygen probe (mV) for different carbon potentials in an atmosphere consisting of 100% cracked methanol and 0% nitrogen.

Table 6b: Output signal from an oxygen probe (mV) for different carbon potentials in an atmosphere consisting of 60% cracked methanol and 40% nitrogen.

Table 6c: Output signal from an oxygen probe (mV) for different carbon potentials in an atmosphere consisting of 20% cracked methanol and 80% nitrogen.

Appendix 1

Table 4a: Dew point (°C) for different carbon potentials in an atmosphere consisting of 100% cracked methanol and 0% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	45.2	44.1	42.9	41.8	40.6	39.5	38.3	37.2	36.1	34.9	33.8	32.6	31.5	30.4	29.3	28.2	27.2	26.1	25.1
0.25	41.9	40.7	39.6	38.4	37.2	36.0	34.8	33.6	32.5	31.3	30.1	29.0	27.9	26.8	25.7	24.6	23.5	22.4	21.4
0.30	39.1	37.9	36.7	35.4	34.2	33.0	31.8	30.6	29.4	28.3	27.1	26.0	24.8	23.7	22.6	21.5	20.5	19.4	18.4
0.35	36.6	35.4	34.1	32.9	31.7	30.4	29.2	28.0	26.8	25.6	24.5	23.3	22.2	21.1	20.0	18.9	17.9	16.8	15.8
0.40	34.4	33.1	31.9	30.6	29.4	28.1	26.9	25.7	24.5	23.3	22.2	21.0	19.9	18.8	17.7	16.7	15.6	14.6	13.6
0.45	32.3	31.1	29.8	28.5	27.3	26.1	24.8	23.6	22.4	21.3	20.1	19.0	17.9	16.8	15.7	14.6	13.6	12.6	11.6
0.50	30.5	29.2	27.9	26.7	25.4	24.2	23.0	21.8	20.6	19.4	18.3	17.1	16.0	14.9	13.8	12.8	11.8	10.7	9.8
0.55	28.7	27.5	26.2	24.9	23.7	22.4	21.2	20.0	18.8	17.7	16.5	15.4	14.3	13.2	12.2	11.1	10.1	9.1	8.1
0.60	27.1	25.8	24.6	23.3	22.1	20.8	19.6	18.4	17.2	16.1	15.0	13.8	12.7	11.7	10.6	9.6	8.6	7.6	6.6
0.65	25.6	24.3	23.0	21.8	20.5	19.3	18.1	16.9	15.8	14.6	13.5	12.4	11.3	10.2	9.2	8.2	7.1	6.2	5.2
0.70	24.2	22.9	21.6	20.4	19.1	17.9	16.7	15.5	14.4	13.2	12.1	11.0	9.9	8.9	7.8	6.8	5.8	4.8	3.9
0.75	22.8	21.5	20.3	19.0	17.8	16.6	15.4	14.2	13.1	11.9	10.8	9.7	8.6	7.6	6.6	5.6	4.6	3.6	2.7
0.80	21.5	20.2	19.0	17.7	16.5	15.3	14.1	13.0	11.8	10.7	9.6	8.5	7.4	6.4	5.4	4.4	3.4	2.4	1.5
0.85	20.3	19.0	17.8	16.5	15.3	14.1	12.9	11.8	10.6	9.5	8.4	7.3	6.3	5.3	4.2	3.3	2.3	1.3	0.4
0.90	19.1	17.8	16.6	15.4	14.1	13.0	11.8	10.6	9.5	8.4	7.3	6.2	5.2	4.2	3.2	2.2	1.2	0.3	-0.4
0.95	-	-	15.5	14.2	13.0	11.9	10.7	9.6	8.4	7.3	6.3	5.2	4.2	3.1	2.1	1.2	0.2	-0.5	-1.3
1.00	-	-	-	13.2	12.0	10.8	9.6	8.5	7.4	6.3	5.2	4.2	3.2	2.2	1.2	0.2	-0.5	-1.3	-2.1
1.05	-	-	-	-	-	9.8	8.6	7.5	6.4	5.3	4.3	3.2	2.2	1.2	0.2	-0.5	-1.3	-2.1	-2.9
1.10	-	-	-	-	-	-	7.7	6.5	5.5	4.4	3.3	2.3	1.3	0.3	-0.4	-1.3	-2.1	-2.9	-3.6
1.15	-	-	-	-	-	-	-	-	4.5	3.5	2.4	1.4	0.4	-0.4	-1.2	-2.0	-2.8	-3.6	-4.4
1.20	-	-	-	-	-	-	-	-	-	2.6	1.5	0.5	-0.2	-1.1	-1.9	-2.7	-3.5	-4.3	-5.1
1.25	-	-	-	-	-	-	-	-	-	-	-	-0.1	-1.0	-1.8	-2.6	-3.4	-4.2	-5.0	-5.8
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.5	-3.3	-4.1	-4.9	-5.7	-6.4
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.0	-4.8	-5.6	-6.3	-7.1
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-6.2	-7.0	-7.7
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-7.6	-8.3
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.9

Table 4b: Dew point (°C) for different carbon potentials in an atmosphere consisting of 60% cracked methanol and 40% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	29.6	28.4	27.2	26.0	24.8	23.6	22.5	21.3	20.2	19.0	17.9	16.8	15.7	14.6	13.6	12.6	11.5	10.5	9.6
0.25	26.2	25.0	23.8	22.6	21.4	20.2	19.0	17.8	16.7	15.5	14.4	13.3	12.2	11.2	10.1	9.1	8.1	7.1	6.1
0.30	23.4	22.1	20.9	19.7	18.5	17.3	16.1	14.9	13.8	12.6	11.5	10.4	9.4	8.3	7.3	6.3	5.3	4.3	3.3
0.35	20.9	19.7	18.4	17.2	16.0	14.8	13.6	12.4	11.3	10.2	9.1	8.0	6.9	5.9	4.9	3.9	2.9	1.9	1.0
0.40	18.7	17.4	16.2	15.0	13.8	12.6	11.4	10.3	9.1	8.0	6.9	5.8	4.8	3.8	2.7	1.8	0.8	-0.0	-0.8
0.45	16.7	15.5	14.2	13.0	11.8	10.6	9.4	8.3	7.2	6.1	5.0	3.9	2.9	1.9	0.9	0.0	-0.8	-1.6	-2.4
0.50	14.9	13.7	12.4	11.2	10.0	8.8	7.7	6.5	5.4	4.3	3.3	2.2	1.2	0.2	-0.6	-1.4	-2.2	-3.0	-3.8
0.55	13.2	12.0	10.8	9.6	8.4	7.2	6.1	4.9	3.8	2.7	1.7	0.6	-0.2	-1.0	-1.9	-2.7	-3.5	-4.3	-5.1
0.60	11.7	10.4	9.2	8.0	6.8	5.7	4.6	3.4	2.3	1.3	0.2	-0.6	-1.4	-2.3	-3.1	-3.9	-4.8	-5.5	-6.3
0.65	10.2	9.0	7.8	6.6	5.4	4.3	3.2	2.0	1.0	0.0	-0.8	-1.7	-2.6	-3.4	-4.3	-5.1	-5.9	-6.7	-7.4
0.70	8.9	7.6	6.4	5.3	4.1	3.0	1.8	0.8	-0.1	-1.0	-1.9	-2.8	-3.7	-4.5	-5.3	-6.1	-6.9	-7.7	-8.5
0.75	7.6	6.4	5.2	4.0	2.9	1.7	0.6	-0.2	-1.2	-2.1	-3.0	-3.8	-4.7	-5.5	-6.3	-7.1	-7.9	-8.7	-9.5
0.80	6.4	5.2	4.0	2.8	1.7	0.6	-0.3	-1.2	-2.2	-3.1	-3.9	-4.8	-5.6	-6.5	-7.3	-8.1	-8.9	-9.6	-10.4
0.85	5.2	4.0	2.8	1.7	0.6	-0.3	-1.3	-2.2	-3.1	-4.0	-4.9	-5.7	-6.6	-7.4	-8.2	-9.0	-9.7	-10.5	-11.3
0.90	4.1	2.9	1.7	0.6	-0.3	-1.2	-2.2	-3.1	-4.0	-4.9	-5.7	-6.6	-7.4	-8.2	-9.0	-9.8	-10.6	-11.3	-12.1
0.95	-	-	0.7	-0.2	-1.2	-2.1	-3.0	-4.0	-4.8	-5.7	-6.6	-7.4	-8.3	-9.1	-9.9	-10.6	-11.4	-12.1	-12.9
1.00	-	-	-	-1.1	-2.0	-3.0	-3.9	-4.8	-5.7	-6.5	-7.4	-8.2	-9.0	-9.8	-10.6	-11.4	-12.2	-12.9	-13.6
1.05	-	-	-	-	-	-3.8	-4.7	-5.6	-6.5	-7.3	-8.2	-9.0	-9.8	-10.6	-11.4	-12.2	-12.9	-13.6	-14.4
1.10	-	-	-	-	-	-	-5.5	-6.3	-7.2	-8.1	-8.9	-9.7	-10.5	-11.3	-12.1	-12.9	-13.6	-14.3	-15.1
1.15	-	-	-	-	-	-	-	-	-8.0	-8.8	-9.6	-10.5	-11.3	-12.0	-12.8	-13.6	-14.3	-15.0	-15.7
1.20	-	-	-	-	-	-	-	-	-	-9.5	-10.3	-11.1	-11.9	-12.7	-13.5	-14.2	-15.0	-15.7	-16.4
1.25	-	-	-	-	-	-	-	-	-	-	-	-11.8	-12.6	-13.4	-14.1	-14.9	-15.6	-16.3	-17.0
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-14.0	-14.8	-15.5	-16.2	-16.9	-17.6
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-15.4	-16.1	-16.8	-17.5	-18.2
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-17.4	-18.1	-18.8
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18.7	-19.4
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-19.9

Appendix 1

Appendix 1

Appendix 1

Table 4c: Dew point (°C) for different carbon potentials in an atmosphere consisting of 20% cracked methanol and 80% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (*°F*)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	-1.3	-2.3	-3.3	-4.3	-5.2	-6.1	-7.1	-8.0	-8.9	-9.7	-10.6	-11.4	-12.2	-13.0	-13.8	-14.6	-15.4	-16.1	-16.8
0.25	-4.0	-5.0	-6.0	-6.9	-7.9	-8.8	-9.7	-10.6	-11.5	-12.3	-13.2	-14.0	-14.8	-15.6	-16.4	-17.2	-17.9	-18.6	-19.3
0.30	-6.2	-7.2	-8.2	-9.1	-10.1	-11.0	-11.9	-12.8	-13.6	-14.5	-15.3	-16.1	-16.9	-17.7	-18.5	-19.2	-20.0	-20.7	-21.4
0.35	-8.1	-9.1	-10.1	-11.0	-11.9	-12.9	-13.8	-14.6	-15.5	-16.3	-17.1	-17.9	-18.7	-19.5	-20.3	-21.0	-21.7	-22.4	-23.1
0.40	-9.8	-10.8	-11.7	-12.7	-13.6	-14.5	-15.4	-16.2	-17.1	-17.9	-18.7	-19.5	-20.3	-21.1	-21.8	-22.5	-23.3	-24.0	-24.6
0.45	-11.3	-12.3	-13.2	-14.1	-15.1	-15.9	-16.8	-17.7	-18.5	-19.3	-20.1	-20.9	-21.7	-22.4	-23.2	-23.9	-24.6	-25.3	-26.0
0.50	-12.6	-13.6	-14.5	-15.5	-16.4	-17.3	-18.1	-19.0	-19.8	-20.6	-21.4	-22.2	-22.9	-23.7	-24.4	-25.1	-25.8	-26.5	-27.2
0.55	-13.9	-14.8	-15.8	-16.7	-17.6	-18.5	-19.3	-20.2	-21.0	-21.8	-22.6	-23.3	-24.1	-24.8	-25.6	-26.3	-27.0	-27.6	-28.3
0.60	-15.0	-16.0	-16.9	-17.8	-18.7	-19.6	-20.4	-21.2	-22.1	-22.9	-23.6	-24.4	-25.1	-25.9	-26.6	-27.3	-28.0	-28.6	-29.3
0.65	-16.1	-17.0	-18.0	-18.9	-19.7	-20.6	-21.4	-22.3	-23.1	-23.9	-24.6	-25.4	-26.1	-26.8	-27.6	-28.2	-28.9	-29.6	-30.2
0.70	-17.1	-18.0	-18.9	-19.8	-20.7	-21.6	-22.4	-23.2	-24.0	-24.8	-25.6	-26.3	-27.0	-27.8	-28.5	-29.1	-29.8	-30.5	-31.1
0.75	-18.1	-19.0	-19.9	-20.8	-21.6	-22.5	-23.3	-24.1	-24.9	-25.7	-26.4	-27.2	-27.9	-28.6	-29.3	-30.0	-30.7	-31.3	-31.9
0.80	-18.9	-19.9	-20.7	-21.6	-22.5	-23.3	-24.1	-24.9	-25.7	-26.5	-27.2	-28.0	-28.7	-29.4	-30.1	-30.8	-31.4	-32.1	-32.7
0.85	-19.8	-20.7	-21.6	-22.4	-23.3	-24.1	-24.9	-25.7	-26.5	-27.3	-28.0	-28.8	-29.5	-30.2	-30.9	-31.5	-32.2	-32.8	-33.5
0.90	-20.6	-21.5	-22.4	-23.2	-24.1	-24.9	-25.7	-26.5	-27.3	-28.0	-28.8	-29.5	-30.2	-30.9	-31.6	-32.2	-32.9	-33.5	-34.2
0.95	-	-	-23.1	-24.0	-24.8	-25.6	-26.4	-27.2	-28.0	-28.7	-29.5	-30.2	-30.9	-31.6	-32.3	-32.9	-33.6	-34.2	-34.8
1.00	-	-	-	-24.7	-25.5	-26.3	-27.1	-27.9	-28.7	-29.4	-30.2	-30.9	-31.6	-32.2	-32.9	-33.6	-34.2	-34.8	-35.5
1.05	-	-	-	-	-	-27.0	-27.8	-28.6	-29.3	-30.1	-30.8	-31.5	-32.2	-32.9	-33.6	-34.2	-34.8	-35.5	-36.1
1.10	-	-	-	-	-	-	-28.5	-29.2	-30.0	-30.7	-31.4	-32.1	-32.8	-33.5	-34.2	-34.8	-35.4	-36.1	-36.7
1.15	-	-	-	-	-	-	-	-	-30.6	-31.3	-32.0	-32.7	-33.4	-34.1	-34.7	-35.4	-36.0	-36.6	-37.2
1.20	-	-	-	-	-	-	-	-	-	-31.9	-32.6	-33.3	-34.0	-34.7	-35.3	-36.0	-36.6	-37.2	-37.8
1.25	-	-	-	-	-	-	-	-	-	-	-	-33.9	-34.6	-35.2	-35.9	-36.5	-37.1	-37.7	-38.3
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-35.8	-36.4	-37.0	-37.6	-38.2	-38.8
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-36.9	-37.5	-38.1	-38.7	-39.3
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-38.6	-39.2	-39.8
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-39.7	-40.3
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-40.8

Appendix 2

Table 5a: CO_2 content (vol-%) for different carbon potentials in an atmosphere consisting of 100% cracked methanol and 0% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	4.567	4.181	3.824	3.494	3.190	2.910	2.654	2.420	2.206	2.012	1.835	1.673	1.527	1.394	1.273	1.164	1.065	0.974	0.893
0.25	3.834	3.493	3.179	2.892	2.629	2.389	2.171	1.973	1.793	1.631	1.483	1.350	1.229	1.120	1.021	0.932	0.851	0.778	0.712
0.30	3.288	2.984	2.706	2.453	2.224	2.015	1.827	1.656	1.502	1.363	1.237	1.124	1.022	0.930	0.847	0.772	0.704	0.643	0.588
0.35	2.865	2.592	2.344	2.120	1.917	1.733	1.568	1.419	1.285	1.164	1.056	0.958	0.870	0.791	0.720	0.656	0.598	0.546	0.499
0.40	2.527	2.281	2.058	1.857	1.676	1.514	1.367	1.236	1.118	1.012	0.916	0.831	0.754	0.685	0.623	0.567	0.517	0.471	0.431
0.45	2.250	2.027	1.826	1.646	1.483	1.337	1.207	1.089	0.984	0.890	0.806	0.730	0.662	0.601	0.547	0.497	0.453	0.413	0.377
0.50	2.020	1.817	1.635	1.471	1.324	1.193	1.075	0.970	0.876	0.792	0.716	0.649	0.588	0.534	0.485	0.441	0.402	0.366	0.335
0.55	1.826	1.640	1.474	1.325	1.192	1.073	0.966	0.871	0.786	0.710	0.642	0.581	0.527	0.478	0.434	0.395	0.360	0.328	0.299
0.60	1.659	1.489	1.337	1.201	1.080	0.971	0.874	0.788	0.711	0.642	0.580	0.525	0.476	0.432	0.392	0.356	0.325	0.296	0.270
0.65	1.515	1.359	1.219	1.094	0.983	0.884	0.795	0.716	0.646	0.583	0.527	0.477	0.432	0.392	0.356	0.324	0.295	0.269	0.245
0.70	1.390	1.246	1.117	1.002	0.900	0.809	0.727	0.655	0.590	0.533	0.482	0.436	0.395	0.358	0.325	0.296	0.269	0.245	0.224
0.75	1.279	1.146	1.027	0.921	0.827	0.743	0.668	0.601	0.542	0.489	0.442	0.400	0.362	0.328	0.298	0.271	0.247	0.225	0.205
0.80	1.182	1.058	0.948	0.850	0.762	0.685	0.616	0.554	0.500	0.451	0.407	0.368	0.334	0.303	0.275	0.250	0.227	0.207	0.189
0.85	1.094	0.979	0.877	0.786	0.705	0.634	0.570	0.513	0.462	0.417	0.377	0.341	0.308	0.280	0.254	0.231	0.210	0.192	0.175
0.90	1.016	0.909	0.814	0.730	0.655	0.588	0.528	0.476	0.429	0.387	0.349	0.316	0.286	0.259	0.236	0.214	0.195	0.178	0.162
0.95	-	-	0.758	0.679	0.609	0.547	0.492	0.442	0.399	0.360	0.325	0.294	0.266	0.241	0.219	0.199	0.182	0.165	0.151
1.00	-	-	-	0.633	0.568	0.510	0.458	0.412	0.372	0.335	0.303	0.274	0.248	0.225	0.204	0.186	0.169	0.154	0.141
1.05	-	-	-	-	-	0.476	0.428	0.385	0.347	0.313	0.283	0.256	0.232	0.210	0.191	0.174	0.158	0.144	0.132
1.10	-	-	-	-	-	-	0.401	0.361	0.325	0.294	0.265	0.240	0.217	0.197	0.179	0.163	0.148	0.135	0.124
1.15	-	-	-	-	-	-	-	-	0.305	0.275	0.249	0.225	0.204	0.185	0.168	0.153	0.139	0.127	0.116
1.20	-	-	-	-	-	-	-	-	-	0.259	0.234	0.212	0.192	0.174	0.158	0.144	0.131	0.120	0.109
1.25	-	-	-	-	-	-	-	-	-	-	-	0.199	0.181	0.164	0.149	0.136	0.123	0.113	0.103
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	0.155	0.141	0.128	0.116	0.106	0.097
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.133	0.121	0.110	0.100	0.092
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.104	0.095	0.087
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.090	0.082
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.078

Appendix 2

Table 5b: CO_2 content (vol-%) for different carbon potentials in an atmosphere consisting of 60% cracked methanol and 40% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	1.924	1.740	1.573	1.421	1.284	1.161	1.050	0.950	0.859	0.778	0.705	0.640	0.581	0.528	0.480	0.437	0.398	0.363	0.332
0.25	1.577	1.421	1.280	1.153	1.039	0.936	0.844	0.762	0.688	0.622	0.563	0.510	0.462	0.420	0.381	0.347	0.316	0.288	0.263
0.30	1.328	1.193	1.072	0.963	0.866	0.779	0.702	0.633	0.571	0.515	0.466	0.421	0.382	0.346	0.314	0.286	0.260	0.237	0.216
0.35	1.140	1.022	0.917	0.823	0.739	0.664	0.597	0.538	0.484	0.437	0.395	0.357	0.323	0.293	0.266	0.242	0.220	0.200	0.183
0.40	0.994	0.890	0.797	0.714	0.641	0.575	0.517	0.465	0.419	0.378	0.341	0.308	0.279	0.253	0.229	0.208	0.190	0.173	0.157
0.45	0.877	0.784	0.701	0.628	0.563	0.505	0.454	0.408	0.367	0.331	0.299	0.270	0.244	0.221	0.201	0.182	0.166	0.151	0.138
0.50	0.781	0.697	0.623	0.558	0.500	0.448	0.402	0.362	0.325	0.293	0.265	0.239	0.216	0.196	0.178	0.161	0.147	0.134	0.122
0.55	0.701	0.625	0.559	0.500	0.448	0.401	0.360	0.324	0.291	0.262	0.237	0.214	0.193	0.175	0.159	0.144	0.131	0.119	0.109
0.60	0.633	0.565	0.504	0.451	0.404	0.362	0.325	0.292	0.262	0.236	0.213	0.193	0.174	0.158	0.143	0.130	0.118	0.108	0.098
0.65	0.575	0.513	0.458	0.409	0.366	0.328	0.294	0.265	0.238	0.214	0.193	0.175	0.158	0.143	0.130	0.118	0.107	0.098	0.089
0.70	0.525	0.468	0.418	0.374	0.334	0.299	0.269	0.241	0.217	0.195	0.176	0.159	0.144	0.130	0.118	0.108	0.098	0.089	0.081
0.75	0.481	0.429	0.383	0.342	0.306	0.274	0.246	0.221	0.199	0.179	0.162	0.146	0.132	0.120	0.108	0.099	0.090	0.082	0.074
0.80	0.443	0.395	0.352	0.315	0.282	0.252	0.226	0.203	0.183	0.165	0.149	0.134	0.122	0.110	0.100	0.091	0.083	0.075	0.069
0.85	0.409	0.364	0.325	0.291	0.260	0.233	0.209	0.188	0.169	0.152	0.137	0.124	0.112	0.102	0.092	0.084	0.076	0.069	0.063
0.90	0.378	0.337	0.301	0.269	0.241	0.216	0.194	0.174	0.157	0.141	0.127	0.115	0.104	0.094	0.086	0.078	0.071	0.064	0.059
0.95	-	-	0.280	0.250	0.224	0.200	0.180	0.162	0.145	0.131	0.118	0.107	0.097	0.088	0.080	0.072	0.066	0.060	0.055
1.00	-	-	-	0.233	0.208	0.187	0.168	0.151	0.135	0.122	0.110	0.100	0.090	0.082	0.074	0.067	0.061	0.056	0.051
1.05	-	-	-	-	-	0.174	0.156	0.141	0.126	0.114	0.103	0.093	0.084	0.076	0.069	0.063	0.057	0.052	0.048
1.10	-	-	-	-	-	-	0.146	0.131	0.118	0.107	0.096	0.087	0.079	0.071	0.065	0.059	0.054	0.049	0.045
1.15	-	-	-	-	-	-	-	-	0.111	0.100	0.090	0.082	0.074	0.067	0.061	0.055	0.050	0.046	0.042
1.20	-	-	-	-	-	-	-	-	-	0.094	0.085	0.077	0.069	0.063	0.057	0.052	0.047	0.043	0.039
1.25	-	-	-	-	-	-	-	-	-	-	-	0.072	0.065	0.059	0.054	0.049	0.045	0.041	0.037
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	0.056	0.051	0.046	0.042	0.038	0.035
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.048	0.044	0.040	0.036	0.033
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.038	0.034	0.031
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.033	0.030
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.028

Appendix 2

Table 5c: CO_2 content (vol-%) for different carbon potentials in an atmosphere consisting of 20% cracked methanol and 80% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
°C	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000
°F	*1508*	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832*
0.20	0.252	0.225	0.200	0.178	0.159	0.143	0.128	0.114	0.103	0.092	0.083	0.075	0.068	0.061	0.056	0.050	0.046	0.042	0.038
0.25	0.201	0.179	0.159	0.142	0.126	0.113	0.101	0.090	0.081	0.073	0.066	0.059	0.053	0.048	0.044	0.040	0.036	0.033	0.030
0.30	0.166	0.147	0.131	0.116	0.104	0.093	0.083	0.074	0.067	0.060	0.054	0.049	0.044	0.040	0.036	0.033	0.030	0.027	0.024
0.35	0.140	0.124	0.111	0.098	0.088	0.078	0.070	0.063	0.056	0.050	0.045	0.041	0.037	0.033	0.030	0.027	0.025	0.023	0.021
0.40	0.121	0.107	0.095	0.085	0.075	0.067	0.060	0.054	0.048	0.043	0.039	0.035	0.032	0.029	0.026	0.024	0.021	0.019	0.018
0.45	0.106	0.094	0.083	0.074	0.066	0.059	0.053	0.047	0.042	0.038	0.034	0.031	0.028	0.025	0.023	0.021	0.019	0.017	0.015
0.50	0.093	0.083	0.073	0.065	0.058	0.052	0.046	0.042	0.037	0.033	0.030	0.027	0.025	0.022	0.020	0.018	0.017	0.015	0.014
0.55	0.083	0.074	0.066	0.058	0.052	0.046	0.041	0.037	0.033	0.030	0.027	0.024	0.022	0.020	0.018	0.016	0.015	0.013	0.012
0.60	0.075	0.066	0.059	0.052	0.047	0.042	0.037	0.033	0.030	0.027	0.024	0.022	0.020	0.018	0.016	0.015	0.013	0.012	0.011
0.65	0.068	0.060	0.053	0.047	0.042	0.038	0.034	0.030	0.027	0.024	0.022	0.020	0.018	0.016	0.015	0.013	0.012	0.011	0.010
0.70	0.062	0.055	0.049	0.043	0.038	0.034	0.031	0.028	0.025	0.022	0.020	0.018	0.016	0.015	0.013	0.012	0.011	0.010	0.009
0.75	0.056	0.050	0.044	0.040	0.035	0.031	0.028	0.025	0.023	0.020	0.018	0.016	0.015	0.013	0.012	0.011	0.010	0.009	0.008
0.80	0.052	0.046	0.041	0.036	0.032	0.029	0.026	0.023	0.021	0.019	0.017	0.015	0.014	0.012	0.011	0.010	0.009	0.008	0.008
0.85	0.048	0.042	0.038	0.033	0.030	0.027	0.024	0.021	0.019	0.017	0.016	0.014	0.013	0.011	0.010	0.009	0.009	0.008	0.007
0.90	0.044	0.039	0.035	0.031	0.028	0.025	0.022	0.020	0.018	0.016	0.014	0.013	0.012	0.011	0.010	0.009	0.008	0.007	0.007
0.95	-	-	0.032	0.029	0.026	0.023	0.020	0.018	0.016	0.015	0.013	0.012	0.011	0.010	0.009	0.008	0.007	0.007	0.006
1.00	-	-	-	0.027	0.024	0.021	0.019	0.017	0.015	0.014	0.012	0.011	0.010	0.009	0.008	0.008	0.007	0.006	0.006
1.05	-	-	-	-	-	0.020	0.018	0.016	0.014	0.013	0.012	0.010	0.009	0.009	0.008	0.007	0.006	0.006	0.005
1.10	-	-	-	-	-	-	0.017	0.015	0.013	0.012	0.011	0.010	0.009	0.008	0.007	0.007	0.006	0.005	0.005
1.15	-	-	-	-	-	-	-	-	0.013	0.011	0.010	0.009	0.008	0.008	0.007	0.006	0.006	0.005	0.005
1.20	-	-	-	-	-	-	-	-	-	0.011	0.010	0.009	0.008	0.007	0.006	0.006	0.005	0.005	0.004
1.25	-	-	-	-	-	-	-	-	-	-	-	0.008	0.007	0.007	0.006	0.005	0.005	0.005	0.004
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	0.006	0.006	0.005	0.005	0.004	0.004
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.004	0.004	0.004
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.004	0.004	0.004
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.004	0.003
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.003

Appendix 3

Table 6a: Output signal from an oxygen probe (mV) for different carbon potentials in an atmosphere consisting of 100% cracked methanol and 0% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	1019.2	1020.2	1021.4	1022.5	1023.8	1025.1	1026.4	1027.8	1029.3	1030.7	1032.2	1033.8	1035.4	1037.0	1038.6	1040.2	1041.9	1043.6	1045.3
0.25	1029.0	1030.3	1031.6	1033.0	1034.4	1035.9	1037.5	1039.0	1040.6	1042.3	1043.9	1045.6	1047.4	1049.1	1050.9	1052.7	1054.5	1056.3	1058.1
0.30	1037.4	1038.9	1040.4	1041.9	1043.5	1045.1	1046.8	1048.5	1050.2	1052.0	1053.8	1055.6	1057.4	1059.3	1061.2	1063.1	1065.0	1066.9	1068.8
0.35	1044.8	1046.4	1048.0	1049.6	1051.4	1053.1	1054.9	1056.7	1058.5	1060.4	1062.3	1064.2	1066.2	1068.1	1070.1	1072.1	1074.1	1076.1	1078.1
0.40	1051.4	1053.1	1054.8	1056.6	1058.4	1060.2	1062.1	1064.0	1065.9	1067.9	1069.9	1071.9	1073.9	1075.9	1078.0	1080.0	1082.1	1084.2	1086.3
0.45	1057.4	1059.2	1061.0	1062.8	1064.7	1066.7	1068.6	1070.6	1072.6	1074.7	1076.7	1078.8	1080.9	1083.0	1085.1	1087.2	1089.3	1091.5	1093.6
0.50	1062.9	1064.8	1066.7	1068.6	1070.6	1072.6	1074.6	1076.7	1078.7	1080.8	1082.9	1085.1	1087.2	1089.4	1091.5	1093.7	1095.9	1098.1	1100.3
0.55	1068.0	1069.9	1071.9	1073.9	1076.0	1078.0	1080.1	1082.2	1084.4	1086.5	1088.7	1090.9	1093.1	1095.3	1097.5	1099.7	1102.0	1104.2	1106.5
0.60	1072.8	1074.8	1076.8	1078.9	1081.0	1083.1	1085.3	1087.4	1089.6	1091.8	1094.0	1096.3	1098.5	1100.8	1103.1	1105.3	1107.6	1109.9	1112.2
0.65	1077.3	1079.4	1081.5	1083.6	1085.7	1087.9	1090.1	1092.3	1094.5	1096.8	1099.1	1101.3	1103.6	1105.9	1108.2	1110.6	1112.9	1115.2	1117.5
0.70	1081.6	1083.7	1085.8	1088.0	1090.2	1092.4	1094.7	1096.9	1099.2	1101.5	1103.8	1106.1	1108.4	1110.8	1113.1	1115.5	1117.8	1120.2	1122.6
0.75	1085.7	1087.8	1090.0	1092.2	1094.4	1096.7	1099.0	1101.3	1103.6	1105.9	1108.3	1110.6	1113.0	1115.4	1117.7	1120.1	1122.5	1124.9	1127.3
0.80	1089.6	1091.7	1094.0	1096.2	1098.5	1100.8	1103.1	1105.4	1107.8	1110.2	1112.5	1114.9	1117.3	1119.7	1122.1	1124.6	1127.0	1129.4	1131.9
0.85	1093.3	1095.5	1097.8	1100.1	1102.4	1104.7	1107.0	1109.4	1111.8	1114.2	1116.6	1119.0	1121.5	1123.9	1126.3	1128.8	1131.3	1133.7	1136.2
0.90	1096.9	1099.1	1101.4	1103.7	1106.1	1108.4	1110.8	1113.2	1115.6	1118.1	1120.5	1123.0	1125.4	1127.9	1130.4	1132.8	1135.3	1137.8	1140.3
0.95	-	-	1104.9	1107.3	1109.7	1112.1	1114.5	1116.9	1119.3	1121.8	1124.3	1126.7	1129.2	1131.7	1134.2	1136.7	1139.2	1141.8	1144.3
1.00	-	-	-	1110.7	1113.1	1115.5	1118.0	1120.4	1122.9	1125.4	1127.9	1130.4	1132.9	1135.4	1137.9	1140.5	1143.0	1145.5	1148.1
1.05	-	-	-	-	-	1118.9	1121.4	1123.9	1126.4	1128.9	1131.4	1133.9	1136.4	1139.0	1141.5	1144.1	1146.6	1149.2	1151.8
1.10	-	-	-	-	-	-	1124.7	1127.2	1129.7	1132.2	1134.8	1137.3	1139.9	1142.4	1145.0	1147.6	1150.2	1152.7	1155.3
1.15	-	-	-	-	-	-	-	-	1132.9	1135.5	1138.0	1140.6	1143.2	1145.8	1148.4	1151.0	1153.6	1156.2	1158.8
1.20	-	-	-	-	-	-	-	-	-	1138.6	1141.2	1143.8	1146.4	1149.0	1151.6	1154.3	1156.9	1159.5	1162.1
1.25	-	-	-	-	-	-	-	-	-	-	-	1146.9	1149.6	1152.2	1154.8	1157.5	1160.1	1162.7	1165.4
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	1155.3	1157.9	1160.6	1163.2	1165.9	1168.6
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1160.9	1163.6	1166.3	1169.0	1171.7
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1169.3	1172.0	1174.7
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1174.9	1177.6
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1180.5

Appendix 3

Table 6b: Output signal from an oxygen probe (mV) for different carbon potentials in an atmosphere consisting of 60% cracked methanol and 40% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820 *1508*	830 *1526*	840 *1544*	850 *1562*	860 *1580*	870 *1598*	880 *1616*	890 *1634*	900 *1652*	910 *1670*	920 *1688*	930 *1706*	940 *1724*	950 *1742*	960 *1760*	970 *1778*	980 *1796*	990 *1814*	1000 °C *1832 °F*
0.20	1039.5	1041.1	1042.7	1044.3	1046.0	1047.7	1049.5	1051.3	1053.1	1054.9	1056.8	1058.7	1060.6	1062.6	1064.5	1066.5	1068.4	1070.4	1072.4
0.25	1050.0	1051.7	1053.5	1055.3	1057.1	1059.0	1060.9	1062.9	1064.8	1066.8	1068.8	1070.9	1072.9	1075.0	1077.0	1079.1	1081.2	1083.3	1085.4
0.30	1058.8	1060.7	1062.6	1064.5	1066.5	1068.5	1070.5	1072.6	1074.7	1076.8	1078.9	1081.0	1083.2	1085.3	1087.5	1089.7	1091.9	1094.1	1096.3
0.35	1066.5	1068.5	1070.5	1072.5	1074.6	1076.7	1078.9	1081.0	1083.2	1085.4	1087.6	1089.8	1092.0	1094.3	1096.5	1098.8	1101.1	1103.3	1105.6
0.40	1073.4	1075.4	1077.6	1079.7	1081.9	1084.1	1086.3	1088.5	1090.8	1093.0	1095.3	1097.6	1099.9	1102.2	1104.5	1106.8	1109.2	1111.5	1113.9
0.45	1079.6	1081.7	1083.9	1086.1	1088.4	1090.6	1092.9	1095.2	1097.6	1099.9	1102.2	1104.6	1106.9	1109.3	1111.7	1114.1	1116.5	1118.9	1121.3
0.50	1085.3	1087.5	1089.8	1092.1	1094.4	1096.7	1099.0	1101.4	1103.8	1106.1	1108.5	1110.9	1113.4	1115.8	1118.2	1120.7	1123.1	1125.6	1128.0
0.55	1090.6	1092.9	1095.2	1097.5	1099.9	1102.2	1104.6	1107.1	1109.5	1111.9	1114.4	1116.8	1119.3	1121.8	1124.2	1126.7	1129.2	1131.7	1134.2
0.60	1095.5	1097.8	1100.2	1102.6	1105.0	1107.4	1109.9	1112.3	1114.8	1117.3	1119.8	1122.3	1124.8	1127.3	1129.8	1132.3	1134.9	1137.4	1140.0
0.65	1100.1	1102.5	1104.9	1107.4	1109.8	1112.3	1114.8	1117.3	1119.8	1122.3	1124.8	1127.4	1129.9	1132.5	1135.0	1137.6	1140.2	1142.8	1145.3
0.70	1104.5	1107.0	1109.4	1111.9	1114.4	1116.9	1119.4	1121.9	1124.5	1127.0	1129.6	1132.2	1134.8	1137.4	1140.0	1142.6	1145.2	1147.8	1150.4
0.75	1108.7	1111.2	1113.6	1116.2	1118.7	1121.2	1123.8	1126.4	1128.9	1131.5	1134.1	1136.7	1139.4	1142.0	1144.6	1147.2	1149.9	1152.5	1155.2
0.80	1112.7	1115.2	1117.7	1120.2	1122.8	1125.4	1128.0	1130.6	1133.2	1135.8	1138.4	1141.1	1143.7	1146.4	1149.0	1151.7	1154.4	1157.0	1159.7
0.85	1116.5	1119.0	1121.5	1124.1	1126.7	1129.3	1131.9	1134.6	1137.2	1139.9	1142.5	1145.2	1147.9	1150.6	1153.2	1155.9	1158.6	1161.3	1164.0
0.90	1120.1	1122.7	1125.3	1127.9	1130.5	1133.1	1135.8	1138.4	1141.1	1143.8	1146.5	1149.2	1151.9	1154.6	1157.3	1160.0	1162.7	1165.4	1168.2
0.95	-	-	1128.8	1131.5	1134.1	1136.8	1139.4	1142.1	1144.8	1147.5	1150.2	1153.0	1155.7	1158.4	1161.2	1163.9	1166.7	1169.4	1172.2
1.00	-	-	-	1134.9	1137.6	1140.3	1143.0	1145.7	1148.4	1151.1	1153.9	1156.6	1159.4	1162.1	1164.9	1167.7	1170.4	1173.2	1176.0
1.05	-	-	-	-	-	1143.7	1146.4	1149.1	1151.9	1154.6	1157.4	1160.2	1162.9	1165.7	1168.5	1171.3	1174.1	1176.9	1179.7
1.10	-	-	-	-	-	-	1149.7	1152.5	1155.2	1158.0	1160.8	1163.6	1166.4	1169.2	1172.0	1174.8	1177.6	1180.4	1183.2
1.15	-	-	-	-	-	-	-	-	1158.5	1161.3	1164.1	1166.9	1169.7	1172.5	1175.4	1178.2	1181.0	1183.9	1186.7
1.20	-	-	-	-	-	-	-	-	-	1164.5	1167.3	1170.1	1173.0	1175.8	1178.6	1181.5	1184.3	1187.2	1190.1
1.25	-	-	-	-	-	-	-	-	-	-	-	1173.3	1176.1	1179.0	1181.8	1184.7	1187.6	1190.5	1193.3
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	1182.1	1184.9	1187.8	1190.7	1193.6	1196.5
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1188.0	1190.9	1193.8	1196.7	1199.6
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1196.8	1199.7	1202.6
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1202.6	1205.6
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1208.5

Appendix 3

Table 6c: Output signal from an oxygen probe (mV) for different carbon potentials in an atmosphere consisting of 20% cracked methanol and 80% nitrogen.

C-pot., wt-% C	Furnace temperature, °C (°F)																		
	820	830	840	850	860	870	880	890	900	910	920	930	940	950	960	970	980	990	1000 °C
	1508	*1526*	*1544*	*1562*	*1580*	*1598*	*1616*	*1634*	*1652*	*1670*	*1688*	*1706*	*1724*	*1742*	*1760*	*1778*	*1796*	*1814*	*1832* °F
0.20	1087.4	1089.7	1092.1	1094.5	1096.9	1099.4	1101.8	1104.3	1106.8	1109.2	1111.7	1114.2	1116.7	1119.3	1121.8	1124.3	1126.8	1129.4	1131.9
0.25	1098.5	1101.0	1103.5	1106.0	1108.6	1111.1	1113.7	1116.3	1118.9	1121.5	1124.1	1126.7	1129.3	1131.9	1134.5	1137.2	1139.8	1142.4	1145.1
0.30	1107.8	1110.4	1113.0	1115.6	1118.3	1120.9	1123.6	1126.3	1128.9	1131.6	1134.3	1137.0	1139.7	1142.4	1145.1	1147.9	1150.6	1153.3	1156.0
0.35	1115.9	1118.5	1121.2	1123.9	1126.7	1129.4	1132.1	1134.9	1137.6	1140.4	1143.2	1145.9	1148.7	1151.5	1154.3	1157.1	1159.9	1162.6	1165.4
0.40	1123.0	1125.7	1128.5	1131.3	1134.1	1136.9	1139.7	1142.5	1145.3	1148.2	1151.0	1153.8	1156.7	1159.5	1162.3	1165.2	1168.0	1170.9	1173.7
0.45	1129.4	1132.2	1135.1	1137.9	1140.8	1143.6	1146.5	1149.4	1152.2	1155.1	1158.0	1160.9	1163.8	1166.7	1169.6	1172.5	1175.4	1178.3	1181.2
0.50	1135.3	1138.2	1141.0	1143.9	1146.8	1149.8	1152.7	1155.6	1158.5	1161.4	1164.4	1167.3	1170.3	1173.2	1176.2	1179.1	1182.1	1185.0	1188.0
0.55	1140.7	1143.6	1146.6	1149.5	1152.4	1155.4	1158.4	1161.3	1164.3	1167.3	1170.3	1173.2	1176.2	1179.2	1182.2	1185.2	1188.2	1191.2	1194.2
0.60	1145.8	1148.7	1151.7	1154.7	1157.7	1160.7	1163.7	1166.7	1169.7	1172.7	1175.7	1178.7	1181.8	1184.8	1187.8	1190.8	1193.9	1196.9	1200.0
0.65	1150.5	1153.5	1156.5	1159.5	1162.5	1165.6	1168.6	1171.7	1174.7	1177.8	1180.8	1183.9	1186.9	1190.0	1193.1	1196.1	1199.2	1202.3	1205.3
0.70	1154.9	1158.0	1161.0	1164.1	1167.1	1170.2	1173.3	1176.4	1179.4	1182.5	1185.6	1188.7	1191.8	1194.9	1198.0	1201.1	1204.2	1207.3	1210.4
0.75	1159.2	1162.2	1165.3	1168.4	1171.5	1174.6	1177.7	1180.8	1183.9	1187.0	1190.2	1193.3	1196.4	1199.5	1202.7	1205.8	1208.9	1212.1	1215.2
0.80	1163.2	1166.3	1169.4	1172.5	1175.6	1178.8	1181.9	1185.0	1188.2	1191.3	1194.5	1197.6	1200.8	1203.9	1207.1	1210.3	1213.4	1216.6	1219.8
0.85	1167.0	1170.2	1173.3	1176.4	1179.6	1182.7	1185.9	1189.1	1192.2	1195.4	1198.6	1201.8	1205.0	1208.1	1211.3	1214.5	1217.7	1220.9	1224.1
0.90	1170.7	1173.9	1177.0	1180.2	1183.4	1186.5	1189.7	1192.9	1196.1	1199.3	1202.5	1205.7	1208.9	1212.2	1215.4	1218.6	1221.8	1225.0	1228.2
0.95	-	-	1180.6	1183.8	1187.0	1190.2	1193.4	1196.6	1199.9	1203.1	1206.3	1209.5	1212.8	1216.0	1219.3	1222.5	1225.7	1229.0	1232.2
1.00	-	-	-	1187.3	1190.5	1193.7	1197.0	1200.2	1203.5	1206.7	1210.0	1213.2	1216.5	1219.7	1223.0	1226.3	1229.5	1232.8	1236.1
1.05	-	-	-	-	-	1197.2	1200.4	1203.7	1206.9	1210.2	1213.5	1216.8	1220.0	1223.3	1226.6	1229.9	1233.2	1236.5	1239.8
1.10	-	-	-	-	-	-	1203.7	1207.0	1210.3	1213.6	1216.9	1220.2	1223.5	1226.8	1230.1	1233.4	1236.7	1240.0	1243.3
1.15	-	-	-	-	-	-	-	-	1213.6	1216.9	1220.2	1223.5	1226.8	1230.1	1233.5	1236.8	1240.1	1243.5	1246.8
1.20	-	-	-	-	-	-	-	-	-	1220.1	1223.4	1226.7	1230.1	1233.4	1236.8	1240.1	1243.4	1246.8	1250.1
1.25	-	-	-	-	-	-	-	-	-	-	-	1229.9	1233.2	1236.6	1239.9	1243.3	1246.7	1250.0	1253.4
1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	1239.7	1243.1	1246.4	1249.8	1253.2	1256.6
1.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1246.1	1249.5	1252.9	1256.3	1259.7
1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1255.9	1259.3	1262.7
1.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1262.2	1265.7
1.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1268.6