Carbon Probe

Instruction Manual

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Instruction Manual for Eurotherm Carbon Probe

Change Record

Issue 2 contains the following corrections:

Section 4 add mm to drawing

Section 4.1 paragraph ‘f’ change from 35m to 35mm. Paragraph ‘k’ change from 25m to 25mm.

Section 7.3.2. add ‘your supplier.

Section 9.3 minor changes to wording under OPERATIONAL DIFFICULTIES

Section 10.1 add ‘a 3 Gas Infrared Analyser system’

Section 12 under ‘Aperture required’ change 35m to 35mm.

1. Warranty

Important

To obtain optimum performance and maximum life from your carbon probe, please observe the recommendations contained in this operating manual. In the unlikely event that the sensor develops a fault during the warranty period, please follow these directions in order to assist us to expedite your claim.

1. Carry out the checks listed on the enclosed warranty claim form. This may highlight a problem which is not related to the probe. If the tests reveal that there is a probe malfunction, the data on the warranty claim form will enable us to identify the possible cause so that we can continue to improve the product.

2. Fax back to the supplier the warranty claim form and return the carbon probe in the original packaging.

NOTE: Please remember to retain the probe mounting hardware, i.e. Gland, Fitting etc.

3. On receipt at the supplier, the validity of the warranty claim will be assessed. The terms of the warranty are detailed below. If the claim is accepted the supplier will issue a warranty replacement probe, which will carry the remainder of the warranty period.

NOTE: It is strongly recommended that a spare probe is held in stock by the customer, which can be used whilst the warranty claim is being assessed.

In exceptional circumstances the supplier will issue a warranty replacement to minimise production downtime, conditional on the outcome of the warranty claim assessment. A charge will be made for the probe if the warranty claim is invalid.

1.1 Warranty Terms

The supplier warrants the Eurotherm Carbon Sensor to be free from defects in material and workmanship under normal use and service for a period of 12 months from delivery date. Should failure occur within the warranty period the supplier's obligation under this warranty is limited to replacing or repairing, at its option, the carbon probe. There will be no warranty applicable in the event of breakage resulting from thermal or mechanical shock, misuse, negligence or accident. Installation and operation, as outlined in this operating manual, must be adhered to. In particular, correct burn off techniques must be carried out to prevent soot formation on the probe tip.

For the carbon probe operating at elevated temperatures, warranty is reduced as follows:

- Up to 1000°C - 12 months
- 1000°C – 1050°C - 6 months
- Over 1050°C - no warranty

Your warranty will be invalidated if:

- **The internal components show signs of being tampered with.**
- **The warranty claim form is not submitted.**
- **The probe is not returned to the supplier in its original packing.**

The supplier will not be liable for any consequential damages whatsoever, (including, without limitation, damages for loss of business profits, business loss, business interruption, loss of business information or any other loss) arising out of the use of or inability to use the product, even if the supplier has been advised of the possibility of such damages. In any case, the supplier's entire liability under any provision of this agreement shall be limited to the amount paid for the goods.

2. Introduction

The carbon probe is a consumable item, similar to a thermocouple, which is mounted with its tip in contact with the furnace atmosphere, ideally close to the working zone.

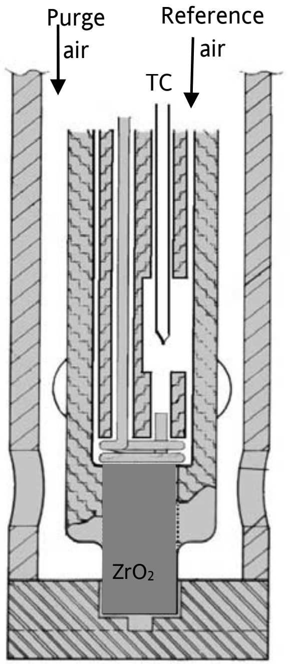
It is used in carbonaceous atmospheres to measure extremely small amounts of oxygen (1×10^{-20}) that is in chemical equilibrium with the CO/CO_2, present in that atmosphere. The probe is in principle a high temperature galvanic oxygen concentration cell constructed of a stabilised zirconium oxide 'plug', welded into the end of an alumina tube using a patented eutectic welding process - the CSIRO sensor.

The zirconia 'plug' is partially dosed with a non-electrolyte to achieve a coefficient of thermal expansion of this composite electrolyte material that matches that of the material of the supporting sensor body, alumina. To each end of the zirconia plug are attached internal and external electrodes. The zirconia acts as a solid electrolyte which conducts electricity by O_2 ions. The sensor is enclosed in a steel alloy protection tube to prevent thermal and mechanical shock, this tube also acts as the outer electrode.

The probe produces an output voltage which in conjunction with the process temperature and atmosphere, can be interpreted in terms of the atmosphere carbon potential of the furnace, see Appendix ‘A’.

An inlet port for the supply of reference air to the inner electrode is located in the head of the probe, along with the electrical connections to the inner and outer electrodes. The probe is generally fitted with a thermocouple to give the process temperature in the probe tip region. The carbon probe is also fitted with a 'burn-off' port to allow the burn-off of carbon/soot deposits on the sensor tip from time to time.

The probe is designed to be used with most controllers and is compatible with any existing carbon probe.



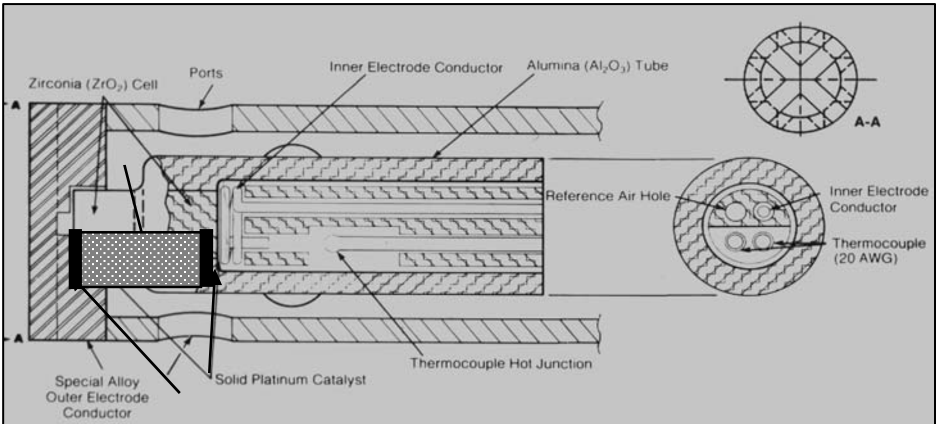


Figure 1-1. Oxygen Sensor Cell Assembly

Carbon Probe Cross Sectional Views

3. Unpacking

The carbon probe, although a robust unit by comparison to other types of carbon probes available, must be unpacked and handled with care.

Each probe is despatched in a secure pack.

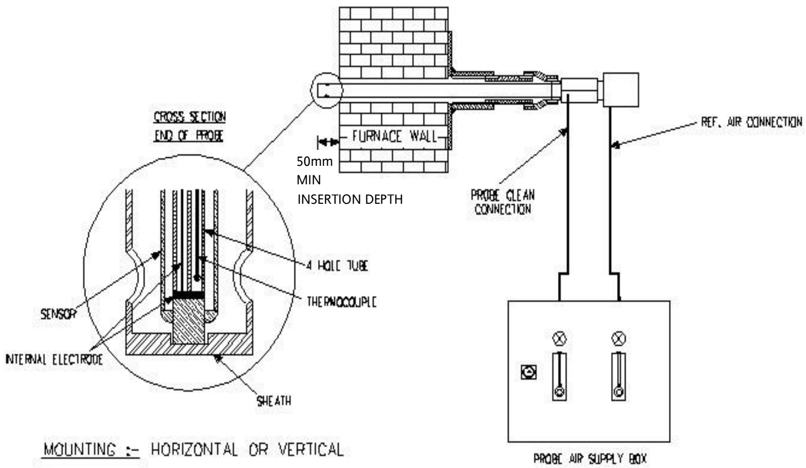
THIS PACK SHOULD BE KEPT IN A SAFE PLACE AT ALL TIMES, SHOULD THE NEED ARISE TO RETURN THE PROBE TO THE SUPPLIER. ANY PROBE NOT BEING RETURNED IN ITS ORIGINAL PACKAGING MAY INVALIDATE THE WARRANTY.

The pack consists of an outer box and an inner pack of polyurethane which houses the carbon probe.

Each pack includes the probe together with the Operating Manual, Warranty Claim Form, Certificate of Conformity and a bag of fittings.

4. Installation

The following are important for correct oxygen probe installation.



4.1 Mechanical

a. Probes can be mounted vertically or horizontally. The only problem this may cause is for probes mounted horizontally in excess of 1000mm un-supported length or for prolonged high temperature operation.

b. Locate the probe near furnace control thermocouple, if possible.

c. Locate the probe away from localized heat sources to avoid unnecessary close contact (i.e. radiant tubes, heating elements).

d. Locate the probe away from atmosphere inlets.

e. Locate the probe so that it operates in the upper area of the work zone if possible.

f. Probe access hole through the furnace lining should be 35mm diameter minimum.

g. Ensure centre lines of the access hole and pipe couplings are concentric for correct line up.

h. Ensure that the fixing to the furnace casing is gas tight.

i. Ensure gas tight connections on ALL external fittings adjacent to the probe.

NOTE- The carbon probe is supplied as standard with a 'burn-off' port. If the port is not to be used ensure that it is plugged, and the plug is fully tightened and that thread sealant is used to obtain a gas tight seal.

j. Install the probe so that the minimum insertion depth into the hot zone is 50 to 100mm. Note: If the insertion length needs to be reduced, use a suitable stand of tube to decrease effective length.

k. The Eurotherm carbon probe, unlike other probes available, has a high resistance to thermal shock and can be inserted or withdrawn from a hot furnace without sensor fracture problems. However, as a precaution introduce (or remove) the probe into a hot furnace in stages of 25mm per minute. Do not place a hot probe on a cold shop floor.

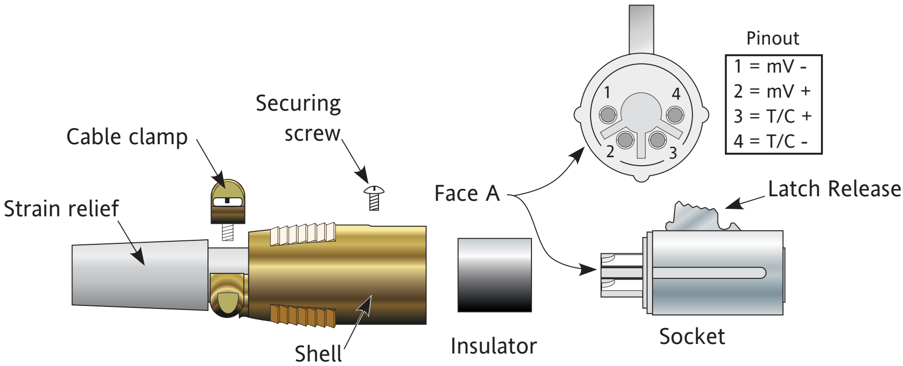
IMPORTANT: WHEN SCREWING THE CARBON PROBE IN OR OUT OF THE PIPE FITTING, USE THE ADJUSTING GLAND NUT ON THE CARBON PROBE SHEATH. DO NOT UNDER ANY CIRCUMSTANCES USE THE SENSOR HEAD FOR TIGHTENING OR LOOSENING THE PROBE.

l. Connect, hi-temp reference air tubing to the reference air inlet fitting on the probe head box and ensure that the probe is fed with a constant supply of reference air @ 200ml per minute minimum.

m. It is essential that the probe is fitted with an intermittent supply of probe cleaning air. Eurotherm can supply a Probe air supply cabinet, which is a self contained source of reference air and probe clean air. It can be positioned local to the probe eliminating long runs of air piping

4.2 Electrical Connections

Use 16/0.2mm twisted twin cable between the probe and the controller, up to a maximum length of 30 metres. If a thermocouple is included in the probe assembly, use the appropriate compensating cable. High temperature-rated (e.g. silicone rubber insulated) cable is essential for connections to the probe and over any part of the cable run which is subject to high temperatures. For the remainder of the run, screened cable should be used. Screens should be connected to ground at the instrument end only.



DIN Plug Wiring

4.3 Measuring Systems

The Eurotherm carbon probe is designed to be used with any Carbon potential controller. However, the carbon probe may be used with any high impedance measuring system. At operating temperatures the sensor impedance is typically 5K - 50K ohms. Measuring systems with input impedances of 10 Meg ohms or higher are recommended. If an instrument with a low impedance 'front end ' is used the effect will be to depress/lower the probe millivolt signal, resulting in inaccurate readings

5. Theory of Operation

When the zirconia cell is subjected to different oxygen partial pressures at its electrodes, a voltage is generated, which is used to calculate the partial pressure at the outer electrode, according to the NERNST equation, i.e.

$pO_2 = f\ (pO_2\ ref\ ,\ T\ ,\ V\ )$ ....(1)

where pO_2 is the oxygen partial pressure at the outer electrode (atmos)

pO_2 ref is the oxygen partial pressure at the inner electrode (0.209 atmos)

T is the cell temperature (°K)

V is the cell voltage (v)

In gas carburising applications a voltage in the range 1000 - 1250 millivolts is generated, see Appendix ‘A’.

6. Operating Range

The internal resistance of the cell, i.e. the resistance through the electrolyte between the electrodes, decreases approximately exponentially with increasing temperature and it is recommended that the probe be used at temperatures above 600°C only.

The maximum temperature at which the cell can be used is limited by two factors,

a. Onset of electronic conduction in the solid electrolyte which will reduce the measured potential below the theoretical value, and

b. Deterioration of the outside electrode, which in the case of the Eurotherm carbon probe, is in the form of the outer protection sheath.

The point at which electronic conduction occurs is a function of both oxygen partial pressure and temperature and for stabilised zirconia it occurs at low oxygen pressures and at high temperatures. As soon as electronic conduction commences it will rapidly increase in degree as the temperature increases, or, as the oxygen partial pressure decreases. It is recommended that the probe be used within the 600°C to 1050°C temperature band.

Electronic conduction will not occur in gas carburising and carbo-nitriding furnace atmospheres due to the temperatures involved.

7. Probe Care / Maintenance

The Eurotherm carbon probe requires no mechanical maintenance and any attempt to dismantle it within the warranty period will invalidate the warranty. The integrity of any atmosphere control system depends on the sensor/measurement device. In the case of oxygen probes (carbon sensors) this is certainly the case as the probe is most often in situ and subject to many different types of abuse.

7.1 Reference Air

A constant flow of Reference Air (0.2 – 0.7 l/min.) is used to maintain the accuracy of the Carbon Probe. Reference air should be clean and free from airborne contamination. Compressed air should not be used. If combustion air is used this should be filtered. Eurotherm can provide a probe air supply cabinet, which provides separate air pumps for reference air and probe cleaning air.

CHECK AND ADJUST as necessary, at least ONCE PER DAY.

7.2 Probe Cleaning

Over 80% of probe failures in service are due to excessive carbon build up on the probe, this is more commonly described as sooting. This can, however, be prevented by regular probe cleaning, or 'burn off', using air if the variables are understood. The important factors affecting efficient probe burn off are:-

- Furnace atmosphere pressure/velocity around the probe.
- The flow of burn of air.
- Temperature increase at the probe tip.

When air is forced down the probe sheath a combustion reaction takes place with the furnace atmosphere, this is an exothermic reaction causing a local rise in temperature. The reaction interface settles at a point down the length of the probe, see below Fig 1.

As the flow of burn off air is increased the interface will naturally move down the probe. Carbon will only be removed from the probe if free oxygen is present to react with it and hence burn the carbon away. At the combustion interface oxygen will be used up quickly and there will be very little free oxygen available to react with the carbon.

The interface must therefore pass the tip of the probe in order to ensure effective cleaning at the probe tip.

If sufficient flow is present, then this combustion interface will actually move off the end of the probe entirely, leaving the probe tip in free oxygen, see below Fig 2.

Fig 1

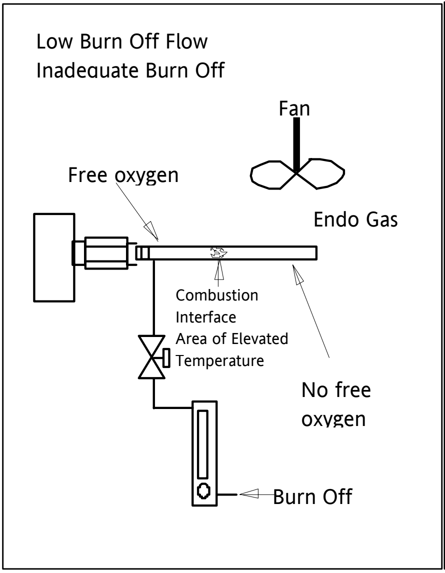
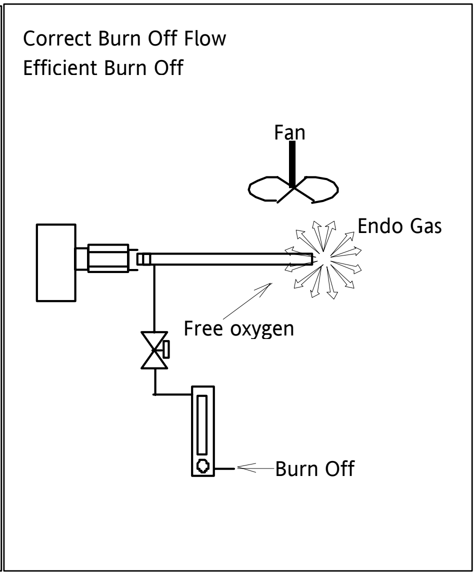


Fig 2



To check for the correct conditions it must be possible to covert the probe mV into percent oxygen, the table below is a guide at 927°C:

O_2 mV	% O_2
1150	9.9×10^{-19}
700	3.6×10^{-11}
100	0.43×10^{1}

Care should be taken to avoid the combustion interface centering on the probe tip, if this is the case the probe temperature may rise by as much as 120°C. It is important to note that the probe tip must be kept below 1000°C to avoid permanently damaging the sensor. Therefore it is important that the burn off flow is adequate when probe cleaning takes place above 900°C

The condition of the furnace atmosphere near the probe is of great importance when establishing the correct flow rate. For example, in one installation a flow of 4 litres/minute was required to overcome the atmosphere but only 1 litre/minute was required when the furnace fan was switched off. (In most cases no more than 4 litres/minute is required).

Probe cleaning normally takes between 3 and 6 minutes. It is best carried out at the start of a cycle to ensure correct operation during the process and may be repeated during long cycles (or periodically in a continuous furnace) to maintain the level of atmosphere control.

Eurotherm can provide a probe air supply cabinet which provides separate air pumps for reference air and probe clean air.

Most carbon controllers have inbuilt facilities to activate the probe cleaning air automatically during the cycle. Alternatively, a timer can be built into the probe air supply cabinet.

WARNING

Inadequate or incorrect probe air cleaning may lead to soot contamination of the probe tip and invalidate the warranty.

CHECK AND ADJUST as necessary, at least ONCE PER DAY.

7.3 Diagnostic Testing

Unfortunately, there is no definitive method for determining the accuracy of an oxygen probe. The only way to establish that the probe is reading accurately is to compare the reading with a reference oxygen probe, carbon foil, or another gas parameter i.e. CO_2 or DEWPOINT.

However, there are several tests that can be performed to give an indication of the probe accuracy.

7.3.1 Electrical Impedance Test

The output impedance of an oxygen probe is a function of the electrode contact area, materials of construction, and temperature. The lower the impedance, the more surface area is in contact with the electrode assembly. A value below 25K ohms at temperature above 800°C is acceptable, once the value rises above 50K ohms it is necessary to change the probe.

Most carbon controllers have inbuilt probe impedance testing. Most instrumentation has this facility – please contact your supplier for details.

CHECK AND RECORD the Probe Impedance on a DAILY basis.

7.3.2 Electrode Response Time

The ability of an Oxygen Probe to recover to its original millivolt reading, after being short circuited, is an important parameter.

To run a test, it is necessary to short circuit the Probe electrodes for 15 seconds, remove the short, and measure the time for the millivolt reading to recover to 99% of its original value. If this time is in excess of 60 seconds, the probe is behaving sluggishly and its accuracy may be in question.

Carry out this test if the Probe integrity is suspected.

Most carbon controllers have inbuilt probe electrode response time testing. Most instrumentation has this facility – please contact your supplier for details.

8. Troubleshooting

8.1 Verify the problem

Verify that the oxygen probe measurement system does in fact disagree with alternative measurement techniques (e.g. Alnor Dewpoint Meter, shim stock analysis, CO_2 or other gas analytical method).

Note: With respect to shim stock tests, be aware that the work's total carbon level requirements may be greatly in excess of the atmosphere levels and times to carburise the shim!

8.2 Instrument and Voltmeter tests

a. Probe thermocouple display on instrument is within ± 10°C of furnace control thermocouple.

b. Process Factor (when using MMI instrumentation), 'CO Factor', or, oxygen probe mV offset is set to the appropriate value.

c. Oxygen mV reading on the instrument agrees with a simultaneous reading from digital voltmeter within ± 6 mV. NOTE: Digital voltmeter to be .5% basic DC accuracy with 10M ohm minimum input impedance, or better in both cases.

d. After the probe is shorted for 15 seconds, it returns to its original reading, ± 10 mV, within 60 seconds (as measured with the voltmeter).

8.3 Reference Air Tests

a. Reference air consists of clean room air, free of airborne contaminants (not compressed air). Try alternative sources of reference air if in doubt.

b. Reference air flow is between 0.2 and 0.7 litres/minute on the flowmeter. The reference air tube can be disconnected at the probe and will bubble in a cup of water (i.e. reference air is definitely getting to the probe).

c. With instrument in manual control mode, shutting of the reference air for 30 seconds should not result in the loss of more than 5 mV on the O_2 mV display.

8.4 Impedance Test

With the probe at 800°C minimum, the probe impedance test yields values in the range of 0.1 to 50K ohm. (Typical readings for the carbon probe will be 5 to 10K ohms).

8.5 Visual Observation

(Observe warnings concerning removal of probe from the furnace.)

a. Probe/Sheath shows no significant accumulation of soot or other deposits (this may mean that the burn off procedure is incorrect and may invalidate warranty).

b. Probe sensor tip, as viewed through the sheath holes, shows no obvious fracture and the sensor appears physically intact.

c. Probe sheath/head box shows no signs of mechanical damage.

9. General Trouble Shooting Guide

9.1 Environment

When installing the system ensure that it is protected from excessive temperature, humidity and vibration. Never run signal cable (sensor, thermocouple or RS485 bus) in the same conduit with power cable. No microprocessor is totally immune from voltage spikes that accompany solenoid, relay or motor activation.

Avoid running reference air tubing in areas where the temperature can exceed 65°C.

Never connect conduit directly to the sensor head because a fractured sensor tube could admit hazardous atmosphere through the conduit to critical instrumentation, equipment or personnel.

9.2 Furnace Maintenance

Carbon is the essential element of the process. It is also, with temperature, the single most damaging factor. It causes refractories to spall and crumble. Furnace alloy deteriorates and quenchants can become contaminated. If the process requires that you operate at carbon potentials significantly in excess of saturation, you must counter the attack by conducting periodic furnace burnouts. With the controller in manual mode and sensor output millivolts displayed, admit air to the furnace (with endogas off, of course!) at about 850°C. Follow the course of the burnout until the sensor output drops below 100mV at which point the burnout is substantially complete. The time necessary to reach this point is a measure of how often burnout should be conducted. All Eurotherm programmable carbon controllers have the capability of programmable burn out control.

9.3 Fault Analysis

When a problem occurs with the process, it is usually the accuracy of the carbon sensor which is brought into doubt. However, there are many other reasons for process malfunction.

The object of this section of the manual is to provide a logical trouble analysis guide.

Before starting a detailed trouble shooting procedure, review all the parameters in the temperature controller and carbon controller. In all too many cases faulty operation can be traced to operator misuse or to a programmed change in a parameter that was not returned to the normal value in the same or subsequent programmes.

Next, determine that the instruments are in proper calibration by inputting millivolt values for sensor and thermocouples and determining correct calibration for millivolt and temperature displays.

The following text is organised by the nature of the problem.

Use the outline to help locate the appropriate part of this section:

A. INCORRECT CASE DEPTH

1. The Harris Equation

B. INCORRECT SURFACE CARBON.

1. Excessive carbon.
2. Low carbon
3. Non-uniform or patchy carbon.

C. OPERATIONAL DIFFICULTIES

1. Short sensor life
2. Excessive time to reach temperature
3. Excessive time to reach carbon
4. Excessive cycling
5. Sooted parts
6. Scale

A INCORRECT CASE DEPTH

A.1 Harris Equation - Although many heat treaters equate shallow case with insufficient carbon in the atmosphere, it should be noted that the case depth is a function only of time and temperature as stated by the Harris Equation:

X = 800[t1/2] / 10(3700/T)

Where X is the case depth in millimetres, t is the time in hours and T is the Absolute Temperature in degrees Kelvin. It is obvious, therefore, that a low surface carbon is not a sign of a shallow case but of an incorrect carbon profile. To achieve the correct profile it may be necessary to increase the controlled carbon potential set point several points above the desired surface carbon. This is due to the fact that the surface of thick sections does not reach equilibrium with the atmosphere until many hours have passed.

For example, at 925°C about 2 hours are required to achieve surface carbon equal to the atmosphere carbon potential. For very thin work pieces such as shim stock between 5 and 8mms thick, equilibrium is achieved in 1 to 1½ hours. For this reason judgement of the correctness of calibration of the carbon analyser should be based on shim stock tests rather than surface carbon measurements.

B. INCORRECT SURFACE CARBON

B.1 Excessive carbon in a work piece is probably the most common of the problems that occur in heat treating. It can usually be related to a calculated carbon potential that is lower than that of the actual furnace atmosphere. This can come about for several reasons which will be stated here in the order of approximate frequency of occurrence.

a. In atmosphere control systems the carbon calculation is dependent on the selected Correction Factor. The Correction Factor, or adjustment to the theoretical carbon potential calculation, can be based on a Process Factor, CO Factor, or, oxygen probe mV Offsets. If the value has been incorrectly set then the calculated %CP will not equate to the actual achieved %CP determined by shim stock or equivalent tests.

b. Endo composition has changed. An increase in carbon monoxide concentration will result in the calculated %C being lower than the actual value. If you find that the effort and expense of maintaining your Endo-generator in precise adjustment is too much for your staff, you may want to investigate the installation of a generator control system.

Furnace generated atmospheres such as Nitrogen/Methanol or 'SuperCarb' are prone to variations in %CO content. All Eurotherm instrumentation has the facilities to input the %CO from an infra-red gas analyser for real-time adjustment of the CO level – please contact for details.

c. A leak developing in the seal at sensor entry or the fan seal or other furnace entries could allow air to be channelled to the sensor, resulting in low readings. An example of this is the development of a radiant tube leak close to the sensor. Combustion products which tend to be slightly oxidising reduce the carbon potential during the high fire cycle. This is recognisable as a cycling of carbon potential in phase with the temperature control cycle.

d. A small crack opens in the sensor tip of the carbon probe allowing the furnace gas and the reference air to mingle resulting in a low millivolt reading. Check for this condition by shifting the display on the controller to sensor millivolts and turning of the reference air. If there is a crack the output will drop at a rate roughly proportional to the size of the crack. When reference air is turned back on, the reading will jump back to the original value. Replace the sensor as soon as possible.

e. Reference air must be pure and uncontaminated by combustibles that could reduce the amount of oxygen in contact with the inner electrode. The reference air supply pumps air from the area to the sensor. If there is a high concentration of natural or enriching gas in the vicinity of the air pump, the sensor will inevitably read low. Fumes from hot Quench Oil could also cause this symptom. Use of plant compressed air supply in place of the standard 'fish pump' supply is to be avoided because the natural lubricants existing or added to the supply will lower the sensor output.

f. An electrical leakage path develops somewhere between the sensor and the measuring instrument. This could be caused by a pinched cable or excessive temperature causing degraded insulation. It could even be caused by a layer of conducting film between the contacts at the sensor or the instrument.

g. A volatile metal such as zinc or lead has been introduced into the furnace and deposited onto the zirconia surface. While little is known about this "poisoning" phenomenon, it is often a cause of incorrect sensor output.

B.2 <u>Low carbon</u> in a work piece can be due to a low temperature, short soak time, faulty circulation due to a slipping fan or to improperly stacked work. It is usually due to an incorrectly calculated %C on the high side:

a. The Correction Factor is, again, an integral part of the %CP calculation. If it is not set correctly then the calculated %CP will be wrong.

b. Endo composition is too low in carbon monoxide.

c. The atmosphere flow holes around the carbon probe tip have become blocked with carbon or other solid materials. As the sensor output is a function of the carbon content of the gas at its surface, the trapped carbon rich atmosphere causes a high sensor reading. Sensor response to sudden atmosphere changes will be sluggish. This phenomenon is common only in furnaces that have not been burnt out on a reasonable schedule as suggested in the introduction to this section. A temporary remedy is to short out the leads to the sensor for a few hours at operating temperature in a normal endogas atmosphere. When this is done, pure reactive oxygen passes from the reference air inside the sensor to the carbon plugged interface and burns away the offending carbon. It is far better, however, to prevent this behaviour by conducting rational periodic burnouts which are beneficial to the furnace and the furnace alloy as well.

d. Poisoning could be a factor as noted previously.

B.3 Non-uniform or patchy carbon is not normally caused by probe or instrument malfunction. It can generally be ascribed to work that has been loaded improperly such that atmosphere cannot freely circulate to critical areas. Faulty circulation due to a slipping fan or displaced brickwork can also be a factor. Diffusion limiting coatings (copper for example) that have not been removed prior to processing can also cause this behaviour.

C. OPERATIONAL DIFFICULTIES

Most of the problems discussed above are related to sensor performance, Correction Factor or furnace equipment malfunction as demonstrated by faulty or off-spec work. Occasionally, problems are perceived during operation that are troublesome or costly but not necessarily a cause of a bad product. The following is a limited list, but will illustrate the reasoning process necessary to solve such problems.

C.1 Short sensor life is one of the most troublesome of all the problems encountered in carbon sensor control of heat treating atmospheres. Although your investment is protected by the supplier's warranty programme, it is nevertheless expensive and inconvenient to replace your carbon probe on a very frequent basis. The vast majority of sensor failures are caused by operation at high carbon potentials without periodic burnout to remove deposited carbon. This is perhaps the most critical part of your preventative maintenance program because it protects your furnace refractory and alloys as well.

Other failure modes that we have documented relate to introduction of corrosive or poisoning materials into the sensor environment. These can originate from salt quench fumes and halogenated degreasing agent carried through into the furnace. Poisoning agents such as zinc or lead introduced into the control zone as galvanised parts or as lubricants in forming operations can cause persistent bias to sensor readings. This bias can occasionally be removed by prolonged burnout treatment to the sensor.

Thermal and mechanical shock breakage of the sensor for whatever reason is considered preventable and therefore cannot be considered as warrantable failures.

When faced with operational difficulties traceable to sensor malfunction, it is important to avoid placing any strain on the small wires in the sensor connection head. When the sensor is operating at elevated temperatures, these wires have virtually no tensile strength and will part easily rendering the sensor useless.

C.2 <u>Excessive time to reach temperature</u> is costly because it reduces furnace productivity. Consider the following possible causes:

a. Reduced fuel pressure caused by a faulty regulator or low pressure from the utility.

b. Reduced combustion air pressure caused by faulty fan belt, or, drive motor.

c. Plugged orifices or valve seats.

d. Scaled or coated radiant tubes.

e. Excessive load size.

f. Low calorific value of fuel.

g. Incorrect P.I.D. Terms on controller.

C.3 <u>Excessive time to reach carbon</u> can have a similar impact and can be traced to some of the following causes:

a. Low enriching gas pressure due to faulty regulator or low pressure from the utility.

b. Low flow rate settings at the flowmeter.

c. Faulty, dirty or out of calibration flowmeter

d. Improper atmosphere circulating fan performance

e. Water in the furnace from a leaking water-cooled fan seal or other source such as incompletely dried new brickwork

f. Wet enriching gas

C.4 Excessive cycling can be caused by too low a proportional band as set in the control parameters. If the excessive cycling is noted in the temperature control, it could also be caused by slow thermocouple response due to fouling or poor contact in the thermowell. A similar effect is noted in carbon control if the atmosphere flow holes in the tip of the carbon probe are plugged.

C.5 Sooted parts are experienced when they are exposed for excessive periods to carbon potentials above saturation levels. Sooting can occur when parts are loaded if a suitably low carbon potential is not established prior to loading.

As the furnace temperature drops, the carbon potential for the existing atmosphere increases. Large, cold loads can drop the temperature in the furnace several hundreds of degrees in a very short time. Enriching gas should never be added until the load is at temperature.

C.6 Scale on parts is usually pre-existing; it was there before the parts were loaded. No significant carburising can occur before the oxide coating is reduced by the atmosphere. If scaling is extensive, it should be removed by pickling or mechanical action before carburising is attempted.

10. APPENDIX A

10.1 Carbon Control

In the gas carburising process, a low carbon bearing carrier gas is used, which is enriched with a hydrocarbon gas, such as propane or methane (natural gas) to increase and control the carbon availability of the atmosphere. The carrier gas is usually of the Endothermic gas type produced from a sub stoichiometric mixture of a hydrocarbon and air at elevated temperature in the presence of a catalyst. The production of Endothermic gas is usually carried out in an external gas generator.

Alternatively, a Nitrogen-Methanol mixture, injected directly into the furnace can be used to produce a synthetic Endothermic gas. Dependent upon the type of hydrocarbon used and the mixture ratio, the typical composition of the carrier gas is;

15 - 25 % CO, 35 - 45 % H_2, Balance N_2,

plus small quantities of CO_2, H_2O, CH_4

The gases CO and CH_4 are carburising, whilst H_2, H_2O and CO_2 are decarburising. In order to control the carbon availability of the atmosphere - the CARBON POTENTIAL, a hydrocarbon gas is used to enrich the carrier gas, by reducing the H_2O (DEWPOINT) according to the reaction:

$CH_4 + H_2O = CO + 3H_2$……………………………….(2)

and by reducing the CO_2 according to the reaction:

$CH_4 + CO_2 = 2CO + 2\ H_2$……………………………..(3)

as well as allowing the following carburising reaction to take place:

$CH_4 = C_{Fe} + 2H_2$………………………………………….(4)

in addition to reaction (4) the other main carburising reactions in a CO - CO_2 - H_2 - H_2O - CH_4 atmosphere are:

$CO + H_2 = C_{Fe} + H_2O$……………………………………(5)

$2CO = C_{Fe} + CO_2$………………………………………….(6)

It has been shown that reaction (5) is10 -100 times faster than reactions (4) and (6), and it is therefore this that is rate determining.

The equilibrium composition of the gases is determined by the 'water – gas' reaction:

$$H_2 + CO_2 = CO + H_2O \quad (7)$$

Combining reactions (5) and (7):

$$2CO = C_{Fe} + CO_2 \quad (6)$$

By using the thermochemical equilibrium constant for the above reaction the carbon activity (ac) of the atmosphere can be calculated:

$$ac = \frac{pCO_2}{pCO_2} K6 \quad (8)$$

Since K6 is temperature dependent only, it can be seen that the carbon activity can be calculated from the CO and CO_2, and since the CO is relatively constant, the CO_2 alone can be used.

We have already seen that the carbon probe measures the small amount of oxygen in equilibrium with the CO and CO_2, which is according to the following reaction,

$$2CO + O_2 = 2\,CO_2 \quad (9)$$

Combining reactions (6) and (9), and using the equilibrium constant to calculate carbon activity,

$$ac = \frac{pCO}{pO_2^{\,0.5}} K10 \quad (10)$$

Hence the Oxygen probe can be used to determine the carbon activity of the atmosphere, and the carbon potential can be shown to be a function of carbon activity (ac), temperature, and steel composition (q).

Therefore:

$$CP = f\,(T, V, CO, q) \quad (11)$$

Where Cp is the Carbon potential (%)

T is the Temperature (°K)

V is the Probe voltage (v)

CO is the Carbon Monoxide (%)

q is the Steel Alloy factor.

The dependence of carbon potential on the steel composition can be explained by the fact that in the presence of alloying elements the effective carbon potential of the atmosphere is increased by elements which form more stable carbides than iron, i.e. Cr, Mo, whereas less strong carbide formers, i.e. Ni, Si, decrease the effective carbon potential.

The complex mathematical calculations necessary to determine the Carbon potential of the atmosphere are built into most controllers. Probe voltage (mV) and temperature are input directly into the instrument, whilst the CO and alloy factor are combined as a constant for a given set of load conditions known as the Correction Factor. The Correction Factor can take the form of terms known as the Process Factor, CO Factor (COF), or, a probe mV offset can be used. Eurotherm % CP controllers include most oxygen probe manufacturer's carbon potential calculations, unique to each manufacturer, and can utilise any of the different Correction Factors to adjust the calculated carbon potential.

For non equilibrium atmospheres or when the CO may not be constant during a cycle, it is possible to input a CO value from an infra red analyser via the instrument's analog input. For absolute carbon control accuracy the Correction Factor can be continuously updated based on the real-time carbon potential calculated from a 3 Gas Infrared Analyser system (CO, CO_2, CH_4). Eurotherm can supply a system, 3G Plus, please ask for details. This system gives the absolute accuracy of 3 gas carbon calculation with the speed of response of oxygen probe control.

11. APPENDIX B

11.1 % Carbon vs. mV Reference Tables

The following tables give %CP vs. probe millivolts at different furnace temperatures for a natural gas (20% CO) and propane (23% CO) reacted endothermic carrier gas.

These tables are based on theoretical calculations and are for EQUILIBRIUM conditions only. For most heat treatment operations, equilibrium conditions rarely exist.

Relationship Between %CP and Probe mV at Various Temperatures for Endothermic Atmospheres Generated from Methane (20% CO)

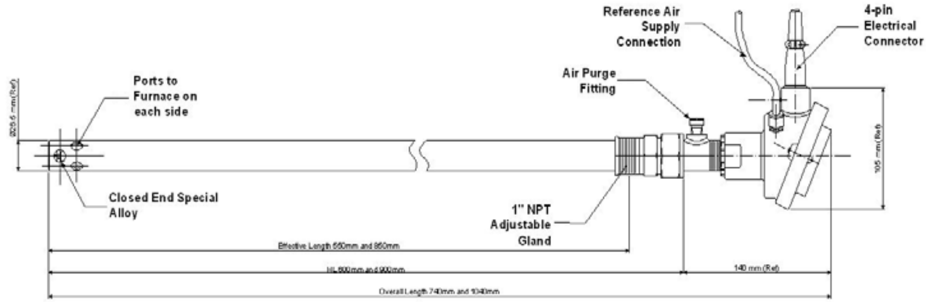
	Temperature °C								
% CP	**800**	**825**	**850**	**875**	**900**	**925**	**950**	**975**	**1000**
0.20	1034	1039	1043	1048	1053	1058	1062	1067	1072
0.25	1043	1048	1053	1058	1063	1068	1073	1078	1083
0.30	1051	1056	1061	1066	1072	1077	1082	1087	1092
0.35	1058	1063	1069	1074	1079	1085	1090	1095	1101
0.40	1065	1070	1076	1081	1087	1092	1098	1103	1109
0.45	1071	1076	1082	1088	1093	1099	1105	1110	1116
0.50	1076	1082	1088	1094	1100	1105	1111	1117	1123
0.55	1082	1088	1094	1099	1105	1111	1117	1123	1129
0.60	1087	1093	1099	1105	1111	1117	1123	1129	1135
0.65	1091	1097	1103	1110	1116	1122	1128	1134	1140
0.70	1096	1102	1108	1114	1120	1127	1133	1139	1145
0.75	1100	1106	1112	1119	1125	1131	1138	1144	1150
0.80	1104	1110	1116	1123	1129	1136	1142	1148	1155
0.85	1107	1114	1120	1127	1133	1140	1146	1153	1159
0.90	1111	1117	1124	1131	1137	1144	1150	1157	1163
0.95	1114	1121	1128	1134	1141	1148	1154	1161	1167
1.00	1118	1124	1131	1138	1144	1151	1158	1165	1171
1.05	1121	1127	1134	1141	1148	1155	1161	1168	1175
1.10	1124	1131	1137	1144	1151	1158	1165	1172	1179
1.15	1127	1133	1140	1147	1154	1161	1168	1175	1182
1.20	1129	1136	1143	1150	1157	1164	1171	1178	1185

Relationship Between %CP and Probe mV at Various Temperatures for Endothermic Atmospheres Generated from Propane (23% CO)

Temperature °C

% CP	800	825	850	875	900	925	950	975	1000
0.20	1027	1031	1036	1041	1046	1051	1055	1060	1065
0.25	1036	1041	1046	1051	1056	1061	1066	1071	1075
0.30	1044	1049	1054	1059	1064	1070	1075	1080	1085
0.35	1051	1056	1062	1067	1072	1078	1083	1088	1094
0.40	1058	1063	1069	1074	1080	1085	1091	1096	1101
0.45	1064	1069	1075	1081	1086	1092	1097	1103	1109
0.50	1069	1075	1081	1087	1092	1098	1104	1110	1115
0.55	1075	1081	1086	1092	1098	1104	1110	1116	1122
0.60	1080	1086	1092	1098	1104	1110	1116	1122	1127
0.65	1084	1090	1096	1102	1109	1115	1121	1127	1133
0.70	1089	1095	1101	1107	1113	1120	1126	1132	1138
0.75	1093	1099	1105	1112	1118	1124	1130	1137	1143
0.80	1097	1103	1109	1116	1122	1128	1135	1141	1148
0.85	1100	1107	1113	1120	1126	1133	1139	1146	1152
0.90	1104	1110	1117	1123	1130	1137	1143	1150	1156
0.95	1107	1114	1120	1127	1134	1140	1147	1154	1160
1.00	1110	1117	1124	1131	1137	1144	1151	1157	1164
1.05	1114	1120	1127	1134	1141	1147	1154	1161	1168
1.10	1117	1123	1130	1137	1144	1151	1158	1165	1171
1.15	1119	1126	1133	1140	1147	1154	1161	1168	1175
1.20	1122	1129	1136	1143	1150	1157	1164	1171	1178

12. Specification



Standard Probe maximum insertion lengths:	**600mm = 550mm; 900mm = 850mm** Maximum Insertion length = the distance from the probe tip to the screwed gland.
Output:	1.00 to 1.20 V dc over operating range.
Temperature range:	760°C to 1100°C
Response time:	Less than 1.0 second.
Accuracy:	± 0.05 weight % carbon in normal operating range.
Range of operation:	Oxygen down to 10^{-30} atmospheres.
Thermocouple:	Types K, R, S, N and No T/C
Maximum head temperature:	150°C
Probe sheath:	Special alloy – resistant to corrosion and oxidisation up to 1100°C
Diameter of sheath:	26.5mm O.D. nominal
Aperture required:	35mm minimum
Fitting detail:	Screwed fitting 1" NPT Male Adjustable Gland
Furnace insertion:	Minimum 75mm, aim 75mm to 100mm
Reference Air Flow:	200ml to 700ml per minute air (20.9% O2)
Warranty period:	12 months from date of despatch

13. Order Codes:

Model	Length (mm)		T-Couple Type
CP		–	
CP = Base Model	**600** = 600mm **900** = 900mm		**0** = No T/C **K** = 'K' Type T/C **N** = 'N' Type T/C **S** = 'S' Type T/C **R** = 'R' Type T/C

For Example: **CP600-K** = 600mm length fitted with a 'K' type Thermocouple.

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